History effects in context: An examination of differential schedule effects in between-subjects, within-subjects, and extinction paradigms.

Morgan, Theresa Anne

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Theresa Anne Morgan

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ProQuest LLC.
789 East Eisenhower Parkway
P.O. Box 1346
Ann Arbor, MI 48106 – 1346

Summary

The effect of history has long been downplayed by strict, behavioural disciplines (Hayes, 1992; Skinner, 1953), where current contingencies are considered paramount in organising behavioural response. However, limited research into latent history effects— wherein differences in an organism's behavioural repertoire not readily apparent in current contingencies can nonetheless be present as a consequence of previous learning— indicates that past experience can play at least a transient role in an organisms' behavioural response. Such effects are particularly salient when schedules of reinforcement are trained in sequence, showing an interaction of old and new contingencies in acquisition stages (Cole, 2001; Freeman & Lattal, 1992) and beyond (Wanchisen, Tatham & Mooney, 1989). Effects of past training can also be readily observed in an extinction condition. The phenomenon where a previously reinforced behaviour can be observed in the absence of reinforcement (Lieving, Hangopian, Long, & O'Connor, 2004) is known as resurgence, and has demonstrated significant incidences in a variety of conditions (see Kazdin, 1994).

The current study presents a three-experiment sequence demonstrating the effect of ratio and interval pretraining on a subsequent fixed-interval schedule (FI) and extinction in a nonhuman population. Rate of response was controlled though use of a yoked-reinforcement procedure, and procedures address within and between subject effects as well as those generated by experimentally naïve and experienced subjects. Results show a transient effect of behavioural history and response rate in historical schedules, with differences between groups diminishing over time. Resurgence of latent differences between ratio and interval histories was then demonstrated in an extinction condition. Results are discussed as regards the role of history effects in an organisms' behavioural repertoire. Similarities and differences in human and nonhuman response sets are also discussed.

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Chapter 1

Learning and Reinforcement History: An Overview

In an experimental context, it is clear that previous learning history can have a wide range of effects on an individual's behaviour. Consider, for instance, an experiment where a human participant is required to push a button for reinforcement. In most cases, this human will already have had countless interactions with a button-pushing paradigm in everyday life, each on a number of different response schedules. It seems fairly intuitive to posit that these experiences will have had an effect on subsequent button-pushing behaviours. An interesting example of this phenomenon occurs daily in New York City, where more than 2,500 of the 3,500 push-button pedestrian signals are actually deactivated from the traffic lights and have been since the late 1980s. Although pushing the button to cross the street actually has no effect on the environment (i.e. it does not expedite a 'walk' signal), previous training has indicated to pedestrians that it does, and the button-pushing behaviour persists (Luo, 2004).

As is clear, past learning can and does have a subsequent effect on behaviour. However, despite this evident effect, the strength, transience, likelihood of occurrence, and specific effect of individual history effects remains difficult to pinpoint. As Tatham and Wanchisen (1998; p. 249) point out, "*behavioural history is a term that has been used loosely for a long time, often to 'explain' otherwise idiosyncratic behaviour" and all too infrequently as the subject for experimentation itself.* In many cases, behavioural history is considered irrelevant in light of current contingencies, where it is assumed that,

given sufficient exposure, the current environment will eventually override any historical training. This is particularly true of behaviour modification theory, where current contingencies are generally the sole focus for any intervention (Kazdin, 1994). This rejection of 'the past' as the critical focus for psychological research may even have its roots in the rejection of Freud and psychoanalysis, causing modern behaviour theory to attend instead only to the current environment. Despite this, even Skinner (1953) noted that any organism's current behaviour is moderated by both its current environment *and* its environmental history. As such, it is clear that the role of historical contingencies in modern behaviour is a theoretically sound approach to experimentation.

Despite the inability to completely isolate such behaviour, history effects have been reliably found in experiments with human populations. Weiner (1964) first found that human participants with fixed-ratio training showed higher rates of response in subsequent fixed-interval schedules. In contrast, those participants with differential-reinforcement-of-low-rate histories showed similarly low rates of response on fixed-interval contingencies. In a subsequent study, Weiner (1969) was able to replicate this effect, although again the lack of control over humans' reinforcement history is posited as a possible modifying variable.

1. Guidelines for Behavioural History Research

1.1 Basic Assumptions

Tatham and Wanchisen (1998, p. 242 -243) suggest three guidelines for behavioural research in the area of history effects: first, it is necessary that "*the research design permit assessment of the effects of an experimental condition on a*

subsequent experimental condition"; second, that "*history effects may be either short-lived or permanent*"; and third, that "*history effects may be observed in ongoing behaviour or may be unobserved until revealed by additional manipulations*". Accordingly, any studies of history effects must fulfil these criteria to qualify as 'true' behavioural history research, regardless of the other experimental foci.

It is clear, however, that these criteria are hardly taxing for most experimenters. The first, "*that the research design permits assessment of the effects of an experimental condition on a subsequent experimental condition*" is fairly intuitive in experimental design. That is, defining the cause-effect relationship between prior and current conditions is the very essence of history effect studies. Tatham and Wanchisen (1998), however, seem primarily concerned with the notion that this relationship be *clearly defined.* They then go on to suggest that, in essence, history effect studies must compare at least two groups on a single test phase to show this relationship: first, one group with a closely controlled history; and second, a group with no history whatsoever, or experimentally naïve animals. Although this can be accomplished as both within- or between-subject designs, it is critical that comparisons between the conditions remain clear.

The second criterion, that "*history effects may be either short-lived or permanent*", allows for discussion of what is referred to as a 'transition state', or a state of behaviour that has not stabilised, and is still in transition from one contingency to another. In previous studies (e.g., Wanchisen, Tatham & Mooney, 1989), the same authors had documented what they saw as permanent history

effects of prior variable-ratio (VR) training on subsequent fixed-interval (FI) performance. This article was later criticised for failing to extend the experiment long enough to allow the effects to fade, thus possibly causing what is actually a temporary effect to appear more lasting (cf. Baron & Leinenweber, 1995). Similar studies have found conflicting results, with history effects ranging from quite lasting and sustained to non-significant. Regardless or duration, however, Tatham and Wanchisen (1998) believe that any effect can be justifiably evaluated through history studies, given that the experiment is cleanly designed.

The third and final criterion for history effects experimentation is that "*history effects may be observed in ongoing behaviour or may be unobserved until revealed by additional manipulations*". In their discussion of this final criterion, Tatham and Wanchisen (1998) are careful to outline differences between easily observable (primarily scheduled) history effects, and somewhat more subtle (such as latent effects, which alter systems other than behaviour, and are often seen in drug trials) history effects. Subtle effects are often of particular interest, in that differences in performance often are only observable under some schedules (such as extinction) and not others. Most important, however, is that the researcher not assume that history effects will extinguish following a manipulation, suggesting that the history of non-naïve animals could have more relevance to subsequent manipulations than is generally assumed.

1.2 Other Variables of Consideration

Okouchi (2003b) posits that the effects of behavioural histories are primarily dependent on three variables: first, the conditions in effect when the history is developed; second, the conditions in effect when the first history is tested; and third, the interactions between the history and the testing effects. As such, it is critically important to clearly define both the training and testing conditions, and to ensure that no prior conditions are impacting the study. This is generally accomplished through the use of experimentally naïve animals (which is impossible to accomplish in a human population for the aforementioned reasons). Further, of most interest, is generally the last variable, or the interaction between the training and testing conditions, be it stimulus (Freeman & Lattal, 1992), interreinforcer interval (Okouchi, 2003b), or simply previous schedule effects (Wanchisen et al., 1989).

As per Tatham and Wanchisen (1995), the focus on the tight control over both past and present conditions during history effects studies is paramount. This makes theoretical sense in any study of history effects, as the very study of this area assumes some effect of past training to be present; as such, it would be contradictory to fail to control and document any such history. As animals are generally kept in controlled environments, this is easy to accomplish in such populations, but nearly impossible for human participants. Rats make particularly ideal subjects in history effects studies, as they are easily trained in simple response (e.g., lever pressing) and their life spans are sufficient to permit the training of various histories.

2. Types of History Effects

2.1 Resurgence

In conditions where the most recently learned response set no longer ensures reinforcement, it becomes increasingly likely that historically reinforced behaviours will be invoked, both in humans (Sajweh, Twatdosz, & Burke, 1972; Weiner, 1964, 1965, 1969; Wilson & Hayes, 1996), and in nonhumans (Mowrer, 1940; Sanders, 1937; Wanchisen, Tatham & Mooney, 1989). In light of Freudian theories, this return to 'the past' to dictate present behaviour was first known as 'regression', but was later renamed 'resurgence' by behaviourists (Epstein & Skinner, 1980). In this case, pigeons were reinforced for key-pecking behaviour, then reinforced at random (not for pecking), then not reinforced at all. Although key-pecking was emitted at the highest rate during the first stage, there was also a heightened incidence of the behaviour at the third and final stage, where no reinforcement was presented at all. As such, the original behaviour experienced a 'resurgence' at the final stage of the experiment despite not being reinforced.

In a behavioural sense, resurgence can be induced using three phases: first, a response (A) is reinforced; second, A ceases to be reinforced (is extinguished) while a second response (B) becomes reinforced (this can either be accomplished through two single steps: extinguishing A, then reinforcing B, or in one step, by failing to reinforce A while simultaneously reinforcing B); and finally, removing reinforcement of B. Resurgence will then occur if A behaviours are performed in the absence of either A or B reinforcement topographies (Lieving, Hagopian, Long, & O'Connor, 2004). In the previous example (i.e. Epstein & Skinner, 1980), stage one was reinforcement for pecking, stage two was delivery of

reinforcement non-contingent on pecking, and stage three was the withholding of reinforcement in its entirety. Though experimental procedures may vary in complexity, they clearly always contain a stage wherein the initially reinforced response is extinguished, with resurgence emerging as a result of a subsequent extinction condition (Lieving et al., 2004).

It has been hypothesised that, given a lack of extinction phase for the first behaviour (A), that A experiences resurgence only because it had previously been replaced with behaviour B, rather than overtly extinguished (Cleland, Foster, & Temple, 2000). In this case, door pushing and head bobbing behaviours were individually reinforced in hens sequentially over time, allowing the 'resurgence' timeline described above to be run through a total of six times. Here, it appeared that at correspondent points during the extinction phases of both door pushing and head bobbing, door pushing behaviours were emitted with similar rates, while head bobbing was not. As door-pushing incidence did not differ significantly between these sessions, while head bobbing did, it suggests that resurgence is due to the failure to properly extinguish a previously learned response. Regardless of cause, however, the event of resurgence itself was clearly observed.

Resurgence is not limited to animal populations, and has been shown to occur in humans using comparatively complicated reinforcement paradigms (Mechner & Jones, 2003; Wilson & Hayes, 1996). In the latter report, previously reinforced key-pressing sequences demonstrated a higher incidence of resurgence in extinction conditions than did novel sequences in a human population, an effect that shows some evidence of resurgence in humans.

2.2 Reinstatement

Reinstatement is said to occur if a previously conditioned response occurs in a contingency where reinforcers are delivered independent of this response. Reinstatement studies usually follow a structure wherein a behavioural response is first conditioned to occur, then eliminated, and then shown to reoccur through response-independent delivery of stimuli that previously functioned as a reinforcer. In one such case, the experimenters first reinforced key-pecking in a pigeon population, then reinforced treadle-pressing with key-pecking no longer being reinforced. Finally, reinstatement was evaluated in response-independent food delivery. Interestingly, in this case the reinstatement condition did not show significant effects in comparison with one of resurgence (extinction) or VI schedule for food delivery contingent on treadle-pressing (Lieving & Lattal, 2003).

One area in which reinstatement is easily demonstrated involves the fear response. Here, subjects are reinforced to criteria and then exposed to extinction for an association between a neutral stimulus and an aversive (feared) stimulus. After extinction has taken place, the feared stimulus is presented alone to re-establish the original fearful response. Reinstatement is particularly strong if it then occurs in a novel or previously unconditioned context, although this is difficult to demonstrate (Bouton, 1984). Evidence also suggests that if a subject is given extensive exposure to extinction after reinstatement (in the form of shocks) is presented, then reinstatement can no longer be observed (Baker et al., 1991).

Reinstatement is also commonly studied in the context of behavioural pharmacology, where classical conditioning of drug effects with a particular

environment can have a significant effect on addiction and biological effect of the drug in question. This has been shown to be particularly true in administration of cocaine, for which stimuli paired with cocaine infusions can show reinstatement effects after extinction (Dewit & Stewart, 1981; Miel & See, 1996). However, similar to schedule based manipulations (Cohen, Peterson, Kinney & Meyers, 1994; Baron & Leinenweber, 1995; Freeman & Lattal, 1992), reinstatement in these types of studies is often transient in nature.

2.3 Primacy and Recency

Primacy and recency effects when they occur together are known as 'serial position effects', and are most easily seen in human memory of lists, where recall or recognition of list items can depend on that item's position on the list (Ward, 2002). Accordingly, primacy occurs when items at the beginning of the list are better recalled than later items, and recency when items falling later in the list are better recalled than those in the front or middle (Mazur, 1994). Often primacy and recency will occur concurrently, with items at the beginning and at the end of a list being preferentially recalled as compared to items falling in the middle. In such a situation, recall shows high levels at the beginning of a list, with steadily declining rates 'troughing' at the middle, and slowly rising to initial levels by the end (see Glanzer & Cunitz, 1966)

In a behaviour paradigm, primacy and recency must instead occur with initial behaviours being preferentially displayed over subsequent ones (primacy), or with later behaviours occurring with more frequency than previous ones (recency). Similarly, Bolhuis and van Kampen (1988) placed rats in a serial-arm

maze with a limited number of arms available. Later, when presented with either entering a previously available arm or entering a new arm with a food reinforcer, rats preferentially entered arms experienced at either the beginning or end of the exposure sessions. This effect has also been shown with tasting behaviour, with rats preferentially consumed flavours presented at the beginning or end of a series of flavours over those presented in the middle (Reed & Croft, 1996).

Harper, McLean & Dalrymple-Alford (1993) showed these effects with some success in male rats using a sequence of arms in a radial arm maze. As such, movement to each individual arm was considered an isolated behaviour, and were exposed to a sequence (or list) or twelve arms. In this case, food was then delayed to determine differences between primacy and recency effects, with recency being more strongly affected than primacy.

The role of serial positioning effects in behaviour training and history studies lies in its interaction with resurgence. That is, primacy and recency are orders in which resurgence can be observed, such as in the case of the serial arm maze preference for recently visited arms over novel ones (Bolhuis & van Kampen, 1988) or in flavour preference for initial and ending flavours over middle ones (Reed & Croft, 1996). These effects are particularly useful when studying a longer series of histories rather than the effect of a single historical paradigm on a subsequent one. For example, Mechner and Jones (2001) trained a human sample on a series of key-presses consisting of a nonsensical sequence of letters. In an extinction continuum, sequences occurring at the beginning of the series and at the end of the series had a higher incidence than did sequences occurring in the

middle. This demonstrates that serial positioning effects like primacy and recency can also be seen in history effect studies.

3. Areas of Special Focus in Historical Effect Studies

Although history effects have been documented in a number of contingencies, including flavour preference (Reed & Croft, 1996), location recall (Bolhuis & van Kampen, 1988), and list recall (Mazur, 1994), and resurgence alone (Epstein & Skinner, 1980; Lieving et al., 2004) certain experimental contingencies have been consistently shown to best display history effects. This includes contingencies such as those involving punishment (where counterintuitive responses can manifest; Kelleher & Morse, 1968), stimulus equivalence (where similar stimuli can encourage equivalent responses; Saunders, Wachter, & Spradlin, 1988), and extinction (where resurgence can best be demonstrated; Epstein, 1983; Mechner & Jones, 2001).

3.1 Punishment

Punishment studies often focus on less readily observable phenomenon such as physiological changes, and generally take place in a pharmacological or psychopharmacological environment. For example, Kelleher and Morse (1968) initially trained squirrel monkeys on variable-interval schedules using food reinforcement. During this schedule, every response during the final minute of each trial was punished with a shock. Although the food was no longer delivered, responses continued and even increased through the administration of shocks. This is highly contradictory behaviour, as the administration of a punishment

(shock) actually appeared to be reinforced by that same stimulus due to previous training linking the shock to a food reinforcement, and despite the fact that the food reinforcement was no longer being delivered.

Kelleher and Morse (1968) argued that this pattern of behaviour showed the ability to maintain a previously conditioned response (lever pressing) despite the use of an FI shock paradigm. More importantly, this showed that history effects could actually overcome current contingencies; that is, by exposing animals first to a procedure wherein responses resulted in avoiding shock, it was then possible to create a condition for which responses not only resulted in shock, but also were also simultaneously maintained by shock. In a similar example, Barret (1977) found that although administration of *d*-amphetamine caused a decrease in lever pressing paired with shock, it also caused an increase in punished responding given that the animals had a history of delayed shock delivery. In this case, the behavioural history (training on delayed shock) clearly had an effect on subsequent behaviour in a punishment continuum.

3.2 Psychopharmacology and Stimulus Control

Moving away from punishment as a sole focus for drug interaction, Nader and Thompson (1987) compared the effects of differing reinforcement schedules on the effects of acute and chronic methadone dosage. Three groups of pigeons were first given identical variable-ratio (VR) 90-sec training under a key-peck response continuum, with 3 differing levels of methadone dosages. Here, pecking a white key was reinforced on a variable-interval (VI) schedule only after first pecking a green key, which was either reinforced under an fixed-ratio (FR) or

differential-reinforcement-of-low-rate (DRL) schedule. Following this, all groups were again returned to their original VI-90-sec schedule.

At first, no significant differences were found between groups on final VI-90-sec performance was found, nor was there a significant effect of methadone administration. On closer examination, however, the authors do note that for a small number of animals the effect of decreasing amounts of methadone was higher for pigeons with a history of low response rates (DRL pre-training). Although non-significant, this suggests a possible interaction between the behavioural history of a subject and the effects of methadone. The authors conclude that schedule histories of low responding seemed to have an impact on the recovery of drug-free baseline behaviours. This clearly supports previous contentions that behavioural history can and does interact with current contingencies in both a biological and behavioural way, although the work is deceptive in that by including pre-training on VI schedules it unnecessarily provides numerous historical contexts to the experimental design. Further, it is possible that the weak results were due to changes in key colour and locations when the VI schedule was put into effect.

This supposition is further supported by Freeman and Lattal (1992), who showed that history effects are strongest when stimuli are consistent throughout schedules. In this case, pigeons were exposed to either a fixed-ratio or differential-reinforcement-of-low-rate schedule using differing conditions for the stimuli. Both groups were then moved to a stimulus-identical variable-interval or fixed-interval schedule for both historical conditions. Here, pigeons that had been exposed to fixed-ratio stimuli showed higher response rates than those exposed to

stimuli associated with the DRL schedule. As such, the authors posit that the effects of prior training were more strongly controlled by stimulus than by schedule, and that when stimuli in both historical and current environments are similar then history effects with be more pronounced and lasting. These results provide evidence that specific characteristics of the stimulus used could also result in differences in subsequent behaviour when similar or identical stimuli are used, and that this effect could even supersede that of the schedule or rate of reinforcement originally associated with such stimuli. As most studies of history effects tend to use innocuous or identical stimuli for each condition (e.g. levers, treadles, lights), evidence that stimuli characteristics are as relevant as manipulation of reinforcement delivery is relatively unique to this study.

This is an unsurprising result, given previous studies in the ability of a stimulus to evoke responses based on previous experience with that stimulus. Wilson and Hayes (1996, p. 267) give the following example:

> "*Suppose that in the presence of a particular unfamiliar stimulus (A1), a person was taught to choose another unfamiliar stimulus (B1) from an array (B1, B2, and B3) and then given B1 as a sample stimulus, to select C1 from another such array (C1, C2, and C3). With this kind of training, the person is also more likely to select B1 given C1 as a sample, C1 given A1 as a sample, and A1 given B1 as a sample.*"

In this situation, previously 'correct' responses are serving as information useful in selecting a subsequent response. As such, information from previously relevant paradigms is being used in currently relevant procedures. This phenomenon is referred to as 'stimulus equivalence' and, if the subject has no other exposure to new stimuli, has effects that have been shown to persist for over

five months in human subjects with developmental disabilities. In this case, three out of four subjects performed at 90% or above accuracy for both initial and later conditions (Saunders, Wachter, & Spradlin, 1988).

3.3 Extinction

When reinforcement is withheld for a previously reinforced behaviour, extinction is said to occur. The application of an extinction contingency has been reported to result in an initial increase in response frequency followed by a gradual decline (Skinner, 1938), a model within which bursts of previously conditioned responses have also been documented (Epstein, 1983; Thomas & Sherman, 1986). This is most often documented as incidences of resurgence of previously reinforced behaviour (see section 2.1). Extinction contingencies result in responses both highly variable and highly indicative of previous training behaviours (Mechner & Jones, 2001).

The term 'extinction-induced resurgence' (Epstein, 1983) refers to the phenomena whereby the training and extinction of a behaviour results in an increased incidence of a previously trained behaviour. As such, extinction studies have taken a large role in the study of history effects and particularly as relates to resurgence within extinction contingencies. This was initially demonstrated in pigeons, where first key pecking was reinforced on an intermittent schedule until a stable response rate was obtained, and then subsequently extinguished. Following a similar training on a second behaviour (for example, wing lifting), extinguishing the second behaviour resulted in a high incidence of key-pecking (25-575 individual occurrences) were recorded. As such, resurgence was considered to be

'extinction-induced', a demonstration that has since been replicated in a variety of paradigms (Lieving & Lattal, 2003; Mechner & Jones, 2001; Rawon, Leitenberg, Mulick, & Lefebvere, 1977; Thomas & Sherman, 1986)

Lieving and Lattal (2003) also experimentally demonstrated the presence of resurgence of previously conditioned responses in an extinction condition. Pigeons were first reinforced to key pecking and then reinforced for treadle pressing (and not for key pecking); finally, neither key pecking nor treadle pressing was reinforced (extinction). Despite the lack of reinforcement for any behaviours, the final phase of the experiment, an increased incidence of key pecking was reported. In a sequence of experiments, the occurrence of historically trained responses (key pecking) was shown to be a repeatable effect that does not function as a result of recency or response-independent food delivery. This reflects findings of Cleland, Foster and Temple (1999) that resurgence is a replicable effect subject to some degree of environmental control. However, further consideration of the role of extinction training in the reappearance of historical continuums needs to take into consideration a number of variables, including number of and length of exposure to extinction conditions.

4. Fixed Interval Schedules

Reinforcement for any particular response can occur along any number of schedules. These schedules dictate how often and by what measurement (e.g., elapsed time since last response, elapsed time since last reinforcement, number of responses by the subject, rate of responses by the subject, quality of response by the subject, etc.) reinforcement will occur (Skinner, 1937; Tarpy, 1982). As

schedules of reinforcement can vary widely, patterns and rate of response can also vary widely according to the type of schedule administered.

The fixed-interval schedule is a type of schedule that produces a highly specific rate and pattern of response over an interval, a response that is particularly marked in animal subjects (Ferster & Skinner, 1957; Mazur, 1994; Ninness, Ozenne, McCuller, Rumph, & Ninness, 2000). As this schedule produces such a characteristic pattern of response, disruptions to that pattern are more easily demonstrated than in schedules with a less particular model. Additionally, it has been hypothesized that the FI schedule results in some degree of inhibitory control: that is, because reinforcement occurs only after a specific amount of time has passed, the delivery of reinforcement actually provides a cue to the animal for subsequent non-delivery until another interval has passed. This may result in the 'post-reinforcement pause' in behaviour that can be observed in most FI contingencies (see Felton & Lyon, 1966 for a review of the post-reinforcement pause). These characteristics make the FI schedule an excellent test phase schedule for studies involving history effects, because if an effect occurs it is generally easier to document than in other contingencies.

4.1 Behavioural Patterns

A fixed-interval is a schedule of reinforcement wherein reinforcement is delivered after a response only after a specific amount of time has passed since the previous reinforcement was delivered (Ferster & Skinner, 1957). This type of schedule typically results in highly characteristic response patterns when using an animal sample. Trials start slowly, generally with a post-reinforcement pause or

extremely limited responses emitted, with responses increasing as the time when the reinforcer will be delivered approaches. Graphing the incidence of responses results in highly recognisable 'scalloping', which appears as a series of asymptotic curves with each curve representing a single trial (Mazur, 1994). The extent to which this scalloping occurs is considered to represent an organism's sensitivity to the schedule, and can be used as a measure of a schedule's strength (Ninness et al., 2000).

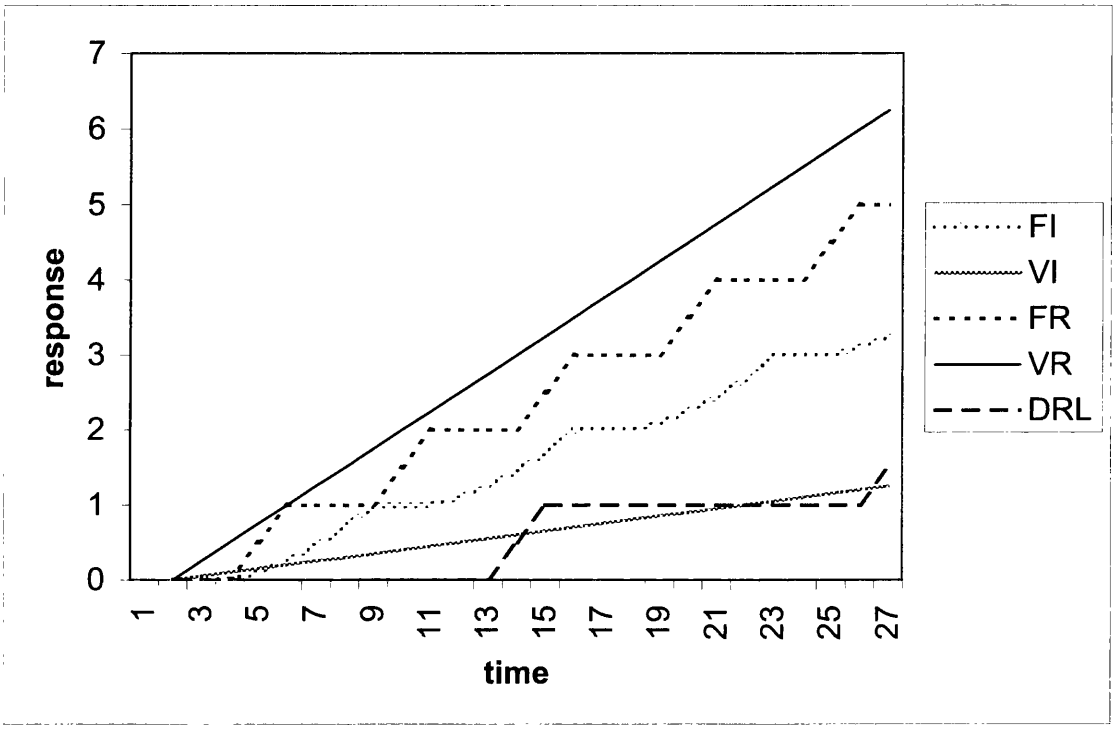

Figure 1.1 Example of nonhuman response on FI (fixed-interval), VI (variable-interval), FR (fixed-ratio), VR (variable-ratio), and DRL (differential-reinforcement-of-low-rate) schedules

In humans, a typical fixed-interval response — with no experimental history documented — will generally result in consistent, undifferentiated

responding across the trial (Mazur, 1994). This phenomenon has been documented in children from the age of four up (Lowe, 1979), where either the aforementioned high rates of response occurred or extremely low rates with just a few responses at the end of the interval were recorded. As such, human responses on an FI schedule appear almost wholly insensitive to the paradigm, and manifest no visible scalloping when graphed.

Although scalloping is the most common response in animals (Figure 1.1), and undifferentiated response is the most common in humans, Hyten and Madden (1993) describe four recognisable patterns of responses on an FI schedule. The first, scalloping (post-reinforcement pause with slowly increasing incidence of response), is described as most commonly seen in animal rather than human samples. The second, break-run (post-reinforcement pause with a sudden high rate of response emitted until termination of the trial), is also described as most commonly seen in animal samples, although subsidiary to scalloping in incidence. Terminal minimum (lengthy post-reinforcement pause with only a few responses at the end of the interval) is noted as most often seen in human samples with low overall response rates. The final pattern is that of a constant rate (where a constant rate of response is issued throughout the interval). The categories of 'other discernable' (patterns not listed above but still easily identified) and 'unclassifiable' (patterns not described above that are generally not replicated with each trial), are also mentioned, although these latter categories are clearly catch-all definitions for otherwise atypical results.

4.2 Behavioural Patterns on Other Schedules

Because the FI schedule produces such characteristic response patterns, it is often used as a target (or final) schedule in history effects studies. To recap, history effects studies generally follow a variation of a three step procedure, including introducing a first schedule (A), then failing to reinforce A whilst simultaneously or sequentially reinforcing a new schedule (B), then failing to reinforce B. This sequence of events is usually then compared to a control sample that has just had training on B. If differences appear between these two groups, then there is generally said to be a history effect of A on B; if these differences show a reappearance of A behaviours, then resurgence is said to occur (Lieving, Hagopian, Long, & O'Connor, 2004).

Within this paradigm, the fixed-interval schedule frequently takes the place of schedule B, or the target schedule. However, selections for schedule A vary. One type of schedule that is frequently used is the fixed-ratio (FR). For this schedule, reinforcement is delivered according to a certain ratio of responses the animal emits. For example, an FR-1 schedule would deliver reinforcement for every one response (i.e. a continuous reinforcement schedule), in an FR-2 schedule, reinforcement for every two responses, and so on (Tarpy, 1982). In an animal population, patterns of response for an FR schedule include a post-reinforcement pause that increases with ratio size (Mazur, 1983) followed by a steady rate of response until the next reinforcement (Figure 1.1).

Similar to the FR schedule, the variable-ratio (VR) schedule delivers reinforcement on a ratio set by the experimenter that operates on a variable basis. For example, if the ratio is set at 4, then an animal may get reinforced at 3, 8, 14,

and 16 total responses. In this pattern of reinforcement, the reinforcement delivery would appear as a bell curve peaking at 4, with most reinforcements occurring around the middle of the curve. This type of reinforcement tends to produce a high, consistent rate of response without the post-reinforcement pauses seen in FI and FR schedules (Mazur, 1994; Tarpy, 1982; see Figure 1.1).

Like the FR schedule, the random-ratio (RR) schedule also delivers reinforcement on a ratio set by the experimenter, with the difference being that each reinforcement is independent from all other reinforcements in the trial (rather than appearing in a bell-curve of delivery), thus making the probability of getting reinforced for each response equal (Knapp, 1997). Usually, this is achieved by assigned a particular probability of reinforcement for each response. For example on an RR-10 schedule, each response would have the probability of reinforcement of 0.1. This schedule also results in high, consistent rates of response, similar to that of the VR schedule.

The variable-interval (VI) schedule is reinforced on an interval that varies according to a mean set by the experimenter (Figure 1.1). Although the graph may appear similar to that of the VR schedule, it is important to note that far fewer reinforcements are delivered within a similar time frame. As such, like the VR schedule, an animal may be reinforced for behaviours after 3, 8, 14, and 16 seconds. In this case, the interval would have been set at four seconds, and reinforcement delivery would appear as a bell curve peaking at four seconds with other intervals distributed normally. As in a VR schedule, the VI schedule results in a steady rate of response. However, this rate is usually much lower than that of

a similar VR, even when all other variables are accounted for (Catania, Matthews, Silverman, & Yohalem, 1977)

A final schedule that is often used in studies of history effects on FI schedules is the differential-reinforcement-of-low-rate (DRL) schedule. In a DRL paradigm, animals are reinforced only for behaviours that have occurred within a set interval of time since the last behaviour. This differs from the FI schedule in that reinforcement is dependent not on the time of the last reinforcement, but on the time of the last behaviour. This schedule encourages very low rates of responding, and is characterised by long periods of no response (as set by the experimenter) followed by single responses (Lejeune, & Jasselette, 1987). A graph of the DRL schedule will look similar to that of the FI schedule (Figure 1.1), the obvious difference being that reinforcement is set dependent on the time of the last behaviour rather than the last reinforcement independent of behaviour. As such, much longer periods of between behaviours (and thus reinforcement) are visible.

4.3 Fixed-Interval Target Schedules with Human Samples

As aforementioned, humans rarely show the classical scalloping pattern associated with animal trials of FI schedules, instead emitting either high or low rates of non-differentiated responses. Interestingly, Catania (1992) describes anecdotal evidence of human scalloping patterns in the case of watch glancing. That is, during a class of a fixed amount of time before a student is permitted to leave (reinforcement), that student will increasingly look at his or her watch during the interval, with frequency seeming to increase as the terminal time is

reached. Unfortunately, Catania does not provide any experimental evidence for this observation, although it would clearly provide a natural example of FI behaviour without resorting to previously reinforced behaviours such as button-pushing.

Far from being novel, the particular FI effect was first documented by Weiner (1964) in a human population. In this case, participants were given non-valued 'points' as reinforcement for button-pressing. Weiner (1964) then ran a series of interconnected studies describing the human FI effect, beginning with a no-history group, and then comparing FR and DRL histories on subsequent FI performance. Here, participants were placed on either a DRL 20-sec (where only responses after 20 seconds of the previous response were reinforced with a point) or a FR 40 (where responses were reinforced after every 40 responses) schedule. Both groups were then moved to a FI 10-sec schedule. Interestingly, Weiner (1964) found that participants in the second group (FR-40) showed much higher overall rates of response than did participants from the first (DRL-20-sec), with the effect lasting for the remaining 20 sessions.

As a consequence of the success of Weiner (1964) in documenting the role of history effects in subsequent performance, a follow-up study (Weiner, 1969) was then performed to replicate and further specify the phenomenon. First, Weiner (1969) ran a group of control subjects solely on fixed-interval contingencies of 10, 30, 60, and 300 seconds. After this baseline had been established, another group of subjects were exposed to either an FR 40 or DRL 20-seconds schedule, after which they were then each exposed to varying FI contingencies. As before, subjects who were given FR training showed

heightened rates of response on FI schedules, while DRL exposed subjects showed much more consistent, low rates of response.

As a follow-up, intra-subject trials were used to replicate the above comparison of FR and DRL training in the same sample. As such, participants from the first sample that had previously been given DRL training were then given FR training, and visa versa. Participants were then re-exposed to fixed-interval conditions (FI 10 sec, FI 30-sec, FI 60-sec, and FI 300-sec) in order of interval length over an hour long trial. As a result, DRL was shown to result in low-rate performances under the FI schedules even after the FR training had preceded DRL exposure. However, high rate performances on FI schedules could not be established after DRL conditioning had already taken place in the same participant. This suggests that the participants have differing sensitivity to FR and DRL histories, with the latter showing more salient effects in FI continuums. Regardless, it was evident that history effects made a considerable difference in subsequent behaviour in this population. Weiner (1969) then went on to further define this relationship, using multiple historical trainings to demonstrate such interactions.

Weiner's (1964, 1965, 1969) series of experiments describing and noting differences in historical exposure on the fixed-interval effect were seminal in developing modern scheduling history effect experiments. Not only was the human fixed-interval response delineated in naïve participants, but also it was then evaluated using the DRL and FR contingencies that are recognised today as one of the most effective pre-training schedules to produce effects in FI environments.

Further, his descriptions of the human response pattern laid the groundwork for continued work in animal samples.

4.4 Fixed-Interval Target Schedules with Animal Samples

In nonhuman animals, a typical fixed-interval response pattern will show first a pause at the onset of each trial, followed by a slowly accelerating rate of response. This results in the classic scalloping pattern that is so characteristic of animal FI training (Dews, 1978; Mazur, 1994; Tarpy, 1982). Comparatively, humans rarely show this scalloping pattern, instead showing a more persistent and standard rate of response across the interval, generally at a fairly high rate and regardless of extensive exposure to the interval schedule (Weiner, 1969, 1970). However, it is the scalloping that is so easily seen in the nonhuman population that is also most easily disrupted by historical paradigms, and has thus become the focus for further experimentation on prior training (Tatham & Wanchisen, 1995).

These discrepancies between human and nonhuman animal performance on FI schedules has been posited as due to the use of naïve animals versus non-naïve humans, thus effectively comparing subjects with no reinforcement history to subjects with an extensive and unknown one. Wanchisen et al. (1989) tested this theory by introducing a controlled reinforcement history in rats, hypothesising that rats with appropriate reinforcement histories would perform similarly to humans on subsequent fixed-interval tasks. As a consequence, subjects were placed in either a history (VR 20) or control (FI 20-sec) groups. Rats in the history group were then run on an A-B-A-B design, exposing them alternately to VR and FI

conditions, while rats in the control group received an equal amount of training, but only on the FI continuum.

As was hypothesised, rats in the history group showed no evidence of the classic scalloping pattern described above, with scalloping type patterns appearing in fewer that 5% of trials for three out of the four rats on this schedule (the fourth showed less than 20% scalloping). Rats in the history group also emitted higher rates of response throughout the session with shorter post-reinforcement pauses. In contrast, the control rats showed standard FI training patterns, including clear evidence of scalloping and low rates. Although it is clear that the VR training resulted in salient changes to the learning process, the authors noted that the history rats showed neither wholly traditional human nor traditional nonhuman patterns of responding on the FI schedule. Data on response rates within trials shows that animals exposed to VR training did show some movement towards developing normal FI patterns; that is, post-reinforcement pauses not seen in VR training began to develop, while overall response rates went down substantially. Critically, the experiment ended before it could be seen whether these patterns would have eventually eroded into standard FI responses, and data analysis was limited and did not include an index of curvature figure to represent the scalloping within trials.

Baron and Leinenweber (1995) sought to rectify these omissions, hypothesising that a similar history — focusing on VR training, as is present in many natural environmental situations — in rats would produce similarly persistent and undifferentiated response patterns as compared to those of humans. In light of the results reported by Weiner (1969), who found that high rates of

response found with a ratio training history declined with an additional history of low response rate schedules, the influence of an extinction schedule was also evaluated as a moderating variable. Nine control animals were only given FI 30 training, while nine test animals were given VR 20 training alone (single) or with 20-minute extinction schedules in between VR sessions. As in Wanchisen et al. (1989), all subjects were then given FI 30 training for 90 sessions.

Initially, results reflected some differences between the groups — animals with previous VR training, for example, manifested higher overall rates of response in comparison with the control subjects. However, on closer examination it was noted that rates within intervals were similar for both groups, indicating sensitivity to the VI paradigm that was not discussed in Wanchisen et al. (1989). As such, the VR history appeared to heighten overall rates of response while still permitting for the eventual development of standard FI patterns (such as lengthening post-reinforcement pauses). Most importantly, the rats did not display the persistent, high rate of response found in human populations in any group, more often displaying the 'break-and-run' pattern (consisting of a post-reinforcement pause followed by high rates of sustained responses). Baron and Leinenweber (1992) criticise Wanchisen et al.'s (1989) conclusion that previous exposure to VR training results in an elevated and undifferentiated response on FI contingencies, similar to human patterns. However, the conclusion that the effects of previous training are gradually reduced over time was supported to some degree in both studies, an effect that occurred regardless of the inclusion of extinction training.

As is clear, it is because of the highly recognisable 'scalloping' and post-reinforcement pauses found in the fixed-interval response set that this schedule is so useful in evaluating history effects of previous schedules. This is particularly true when using history schedules that produce similarly characteristic response rates, such as with variable-ratio schedules — resulting in high rates of consistent, undifferentiated responses — and with DRL — resulting in overall low levels of time separated responses. Although the specific nature of the effect has been under some contention, some effect of response rate on the development of the scalloping pattern has been produced in nearly all studies using this history to FI structure. Further, when measured, there is often a discernable change in the development of a post-reinforcement pause, which is so characteristic of the FI paradigm, but not overtly present in other schedules.

Despite this general focus on high or low rates of response on a history schedule as determinate of effects on a later FI schedule, results have clearly been somewhat inconclusive. Speculation on the comparisons between animals and humans aside, even those experiments with animals have failed to produce any reliably persistent results. Weiner (1969) showed a fairly consistent history effect with humans on FI performance, and Wanchisen et al. (1989) displayed what are likely the most startling results with VR pre-trained rats showing consistent differences in FI performance for the duration of the experiment, with suggestions that the effects were much more far-reaching. However, Baron and Leinenweber (1995), in an effective replication of Wanchisen et al.'s (1989) study failed to produce lasting effects and described the difference between groups as 'transitory'. Freeman and Lattal (1992) similarly showed only transitory changes,

and described the effect as most strong only when associated with similar stimuli and thus suggesting less emphasis on the schedule itself for a pigeon sample. Similarly, Cohen et al. (1994) showed some transitory effects of historical paradigms, but stopped short of seeing any lasting differences (although admittedly, this was on a progressive-ratio (PR) rather than an FI schedule). Clearly this shows a vast difference across species (pigeons, rats, and humans) and paradigms, yet fails to produce any one consistent result that can be reliably replicated.

In light of this knowledge and previous studies (Baron & Leinenweber, 1992; Wanchisen et al., 1989; Weiner, 1964, 1969, 1970), Cole (2001) sought to further clarify the effect of DRL and VR schedules on subsequent FI performance in a rat sample, criticising previous studies inconsistency and explaining differences on the failure of experimenters to carry studies to their limit. Conclusively, Cole (2001) believed that were each of the aforementioned studies extended, that behaviour would eventually have developed with sensitivity only to the primary paradigm (in this case, FI). This unnatural curtailing of experiments before the effects were properly investigated, argues Cole (2001), is at the root of inconsistencies across species, type of history schedule, and even type of target (current) schedule. Cole particularly points to Baron and Leinenweber (1992) and Cohen et al. (1994) as examples of extended training on the most current schedule resulting in dwindling history effects, arguing that all future studies should extend to the point where the disappearance of historical schedule effects occurs. However, this argument only refers to observable history effects; as in Mechner

and Jones (2001), exposure to a new paradigm still may reveal latent effects that are not visible under the current (usually FI) paradigm.

Using ten naïve subjects, Cole (2001) compared the effects of single (FR or DRL alone) or compound (FR and DRL in succession) history schedules prior to FI exposure. To accomplish this, rats were first trained to push a lever for food reinforcement on a continuous (one to one) schedule. After this, rats were then placed in one of five conditions: FI 30, DRL 20-sec, FR 20, DRL 20-sec followed by FR 20, and FR 20 followed by DRL 20-sec, with two rats assigned to each condition. Once rats had reached consistent behaviour on each condition, they were then switched to an FI 30-sec schedule for 80 sessions, after which additional sessions were conducted depending on discernable changes in responses and at the discretion of the experimenter.

Cole's (2001) primary conclusion from this experiment was that the data showed "no evidence that FR and DRL schedule histories permanently affect performance on an FI 30-sec schedule" (p. 49). All subjects eventually emitted responses indistinguishable from the FI 30-sec control subjects, regardless of historical condition. This supports contentions from Baron and Leinenweber (1995) that current paradigms will overcome previous ones, given sufficient time, which contradicts supposition by Wanchisen et al. (1989) that some historical schedules may produce indefinitely occurring results. Interestingly, Cole (2001) also noted that after only half the sessions had been conducted, that the data was more consistent with the lasting-effects hypothesis, showing longer post-reinforcement pauses and high rates of response for FR rats as compared to low rates of response for DRL rats, with all rats eventually showing either scalloping

or break and run patterns. Cole decisively concludes that "Provided that training on FI is sufficiently extensive, schedule history effects dissipate" (p. 50). However, it is also briefly noted that both rats on the FR-DRL-FI sequence showed response rates less than half of that seen in other groups, even at the conclusion of the experiment. This anomaly is reasoned as having occurred possibly due to small sample size, although the sample size was the same for all conditions at two rats per condition.

Using a similar sequence of schedules, Francois and Metzger (1993) contrasted the effects of DRL alone or DRL followed by FR prior training on FI performance. In this case, it was found that the particular schedule directly prior to the FI schedule was the one with an effect on FI performance; that is, rats with only DRL training predictably showed overall lowered rates of response when moved to an FI topography, whereas rats with DRL to FR training showed heightened rates of response. Despite the poor performance of his FR-DRL-FI rats, Cole (2001) argues that his results show a replication of LeFrancois and Metzger (1993) because in all other groups, it was the immediately preceding historical schedule that had the most effect, and that this effect was unaltered by whatever training occurred before.

Lopez and Menez (2004) compared the effects of three different conditioning histories on naïve animals, including continuous reinforcement (FR-1), random interval (RI), and fixed time (FT). FT and RI performance was yoked to subsequent FI performance to ensure that reinforcement rates remained the same across schedules, an exception being the FR-1 schedule, which would obviously produce much higher reinforcement rates than otherwise presented.

Rats were first trained to drink from the reinforcement dipper, thus ensuring that awareness of reinforcement presence and salience was uniform. They were first divided into three groups and exposed to either FR-1, FT or RI topographies. Following this, groups were split and exposed to either FI 30-sec or FI 60-sec schedules, with five rats to each of the six programs of training (FR 1 to FI 30, FR 1 to FI 60; FT to FI 30, FT to FI 60; and RI to FI 30, RI to FI 60).

Lopez and Menez (2004) then compared response rates, curvature of scalloping, and overall rates of response within the group. Similar to Cole (2001) and Baron and Leinenweber (1995), initial results were found to indicate that conditioning history does have some effect on subsequent FI performance. However, these results slowly deteriorated over time, showing only transient effects on FI response and contradicting hypotheses of Wanchisen et al. (1989) that such effects may, in some cases, be more permanent in nature. Although at first, rats with schedule histories showed undifferentiated, disorganised responses, this pattern slowly evolved into easily distinguished scalloping of response. Interestingly, both FR 1 and RI rats showed a relatively constant response rate throughout the interval at first, with slow development of scalloping patterns. As the only group experiencing a substantial drop in reinforcement delivery, FR 1 rats also showed an initial decrease in overall responses throughout the sessions. In contrast, FT rats showed a relative increase in response frequency, similar to that shown by RI rats. Again, evidence suggests that previous histories do produce an interaction with primarily the initial sessions of an FI contingency, and that the specific manifestation of these effects is dependent on the nature of the previous schedule.

5. The Present Thesis' Study

As is clear, the effect of previous schedules on later performance — and in particular, on fixed-interval schedule, which manifest such characteristic scalloping patterns — is somewhat contentious in modern research. The present series of studies posit a two-experiment sequence examining the effects of previous training on fixed-interval schedules, followed by an examination of the manifestation of this pretraining in an extinction paradigm. This sequence will take particular consideration of the work of Wanchisen et al. (1989), whose strong results have proved a catalyst for further study and as yet failed to be replicated in their entirety. Further, subsequent studies such as Baron and Leinenweber (1995), Freeman and Lattal (1992), Cole (2001), and most recently Lopez and Menez (2005), provide evidence that some interaction can be expected between prior ratio training given a fixed-interval follow-up. Mechner and Jones (2001) have also demonstrated some evidence of the reoccurrence of history effects in extinction, and suggest that the effects of different historical training may be seen in this contingency. Results will pay particular attention to quarter-life, overall response rate, and index of curvature, which have previously been determined to be the most indicative of interactions occurring between these schedules (Lopez & Menez, 2005).

Chapter 2

Effects of Reinforcement History on Subsequent Performance Between Subjects

Experimental demonstrations of behavioural history effects occur when past contingencies show some interaction with current contingencies, thereby moderating the traditional behaviours on those schedules that would be expected in naïve animals. It is intuitively obvious that previous training will have some effect on current performance (see Chapter 1 for discussion), and such effects have been shown repeatedly in both humans (Mechner & Jones, 2003; Weiner, 1964, 1969), and non-humans (Baron & Leinenweber, 1995; Freeman & Lattal, 1992; Nader & Thompson, 1987; Okouchi, 2003a; Wanchisen, Tatham & Mooney, 1989). Despite these demonstrations, most research into behaviour tends to focus primarily on the current contingencies, rather than the historical ones, and this area remains relatively under-documented. This relative scarcity of research into behavioural contingencies could be due to a number of issues, as discussed in Chapter 1.

The effect of training history on current behaviour has been readily demonstrated in a human population. Weiner (1964) first demonstrated this effect by exposing humans to either a fixed-ratio (FR) 40 or differential reinforcement of low rate (DRL) 20-sec contingencies, and then comparing subsequent performance on fixed interval (FI) 10-sec contingencies. In this case, participants with the FR 40 history demonstrated much higher rates of response during the FI schedule than did their DRL 20 counterparts. This study clearly showed a difference in response

frequency on a current contingency as a result of a historical one. These results were later replicated by Weiner (1969), who showed high, consistent rates of response, with a lack of the post-reinforcement pause, which usually characterises FI training performance in subjects previously exposed to variable ratio (VR) schedules.

These effects were explored in rats, and perhaps the most dramatic results were found by Wanchisen, Tatham and Mooney (1989), when comparing rats' FI performance with either VR 20 or FI 30 histories. In this case, rats with a 30 session history of VR schedules showed different scalloping patterns in the development of terminal FI response patterns, ultimately developing lower-rate FI behaviour much more quickly than did the naïve controls. Experimental rats also failed to display classic scalloping, instead displaying primarily higher rates of response throughout the session. As expected, control rats exposed only to a history of FI scheduling clearly displayed scalloping patterns, and finally moving into generally low-rates of responding.

Wanchisen et al. (1989) suggested that these data provided strong evidence that experimental history can have a large effect on subsequent performance, pointing out that the results are in contrast to those generally expected of non-human responding. As a result, Wanchisen et al. (1989) posited that comparing human and non-human research is necessarily flawed, due to the lack of control over previous training in human subjects. Wanchisen et al. (1989) also paid special attention to the awareness that rats are generally experimentally naïve subjects when used in studies of history effects, a situation which is impossible to replicate in human populations. This is particularly the case in studies of humans

where participants are reinforced for button pressing, where experience with the behaviour is moderated by an unknown experience with primarily variable-ratio reinforcement. Comparisons between human and non-human performance aside, it remains clear from these results that some effect of previous training can be seen in both subject groups.

Incomplete though the animal model may be, Wanchisen et al. (1989) provide what is probably the most striking example of a VR history effect on subsequent FI performance. This is most clear when naïve animals are compared to VR pre-trained animals where, as previously discussed, animals with the experimental history showed much higher rates of response than did control subjects, with significantly impaired, if not non-existent, scalloping. However, it is possible that given further training, the experimental rats would eventually have displayed behaviour more consistent with their naïve counterparts. As pointed out by Baron and Leinenweber (1995), Wanchisen et al.'s (1989) experimental animals also showed some sensitivity to the experimental (FI) condition; displaying longer post-reinforcement pauses and slowly declining rates of response approaching those of the control group. Later research reflected this finding with pigeons (Freeman & Lattal, 1992), showing an eventual decline of history effects into response patterns characteristic of the newer contingency.

Despite this, it remains clear that there is some degree of history effects on new contingencies, although its strength and specific nature is under some debate. An earlier depiction of such effects comes from Urbain, Poling and Milliam (1978), who compared the effects of either FR 40 or IRT pretraining on subsequent FI 15 schedule performance. In this case, rats exposed to the FR

schedule showed significantly higher rates of responding on the FI 15 schedule than their IRT counterparts, even after training on the FI schedule had exceeded the original training by nearly fifty sessions. Such findings again reflect the drastic, lasting effects found by Wanchisen et al. (1989), where some effects of prior training continued to be seen even after new contingencies had been introduced. Again, however, the experiment was too short to provide clear evidence that the effects of ratio training continue beyond the somewhat stilted limitations of the experiment.

However, subsequent studies have failed to replicate the lasting effects found by Wanchisen et al. (1989), and Urbain et al. (1978). Following Wanchisen et al (1989), Baron and Leinenweber (1995) compared two groups of rats on either single or compound VR schedules, then moved both groups into a FI 30-sec schedule. Although both histories showed the same pattern of high FI rates that declined over time, there were no discernable differences between groups by the conclusion of the experiment, thus providing some support for the argument that rats and humans behave differently regardless of prior training. As noted above, Freeman and Lattal (1995) found only a transitory effect of history training on subsequent FI performance.

The transience of history effects was most recently demonstrated by Lopez and Menez (2005). In this study, groups of rats were trained on FI or FR schedules of reinforcement, after which the rats were given either FI 30-sec or FI 90-sec contingency training. Although differences in patterns of response within the inter-reinforcement interval (IRI) were reported, results reflected previous

findings of transitory and not lasting history effects (Baron & Leinenweber, 1995; Freeman & Lattal, 1995).

Cole (2001) compared the effects of pretraining on FR and DRL schedules when moved to an FI paradigm. In this case, histories were more complicated, including FR-20, DRL-20-sec, or both schedules (alternating order) prior to the FI-30-sec exposure. At first, Cole (2001) found that FI performance was affected by the previous schedule, showing the expected low (after DRL), or high (after FR), rates of response throughout the session. However, as suggested by Baron and Leinenweber (1992), and Freeman and Lattal (1995), after extended training (100 sessions) there was no discernable difference between the groups, providing evidence that the effects found by Wanchisen et al. (1989) could have been transient in nature.

Although it is clear that some history effects have been noted in rat populations, the effect has ranged from small and transient (as in Freeman & Lattal, 1992; Cole, 2001) to much more significant and lasting (as in Wanchisen et al., 1989). As such, the size and specific nature of pretraining effects has remained in some dispute. The present study seeks to clarify the role that history plays in subsequent learning, with a specific focus on FI training as this is the paradigm most observed to moderate later learning. In particular, after consideration of work by Freeman and Lattal (1995), Wanchisen, Tatham and Mooney (1989), and Cole (2001), the current study proposes that there will be a measurable effect of prior random ratio (RR) schedule training on subsequent FI behaviour in a rat population; further, it is posited that this effect will take the form of slightly retarded performance in pretrained rats on subsequent FI

schedules. It is also posited that this effect will show some movement towards response rates more characteristic of current contingencies.

Although the effects of schedules with lower rates of response than RR schedules on subsequent FI performance have been examined (Cole, 2001), previous research has not examined schedules with lower rates of response but similar rates of reinforcement. By setting rates of reinforcement to equal those of the VR schedule, the impact of response rate, independent of reinforcement rate, on history effects can better be examined. The current study intends to equate RI reinforcement to that of RR reinforcement through use of a yoking procedure, with the expectation that some disruption of subsequent FI performance will still occur in the absence of differential rates of reinforcement.

Method

Subjects

Twenty-four, male Wistar rats were maintained at 85% of their free-feeding weight for the duration of the experiment. They were housed in groups of four, with water readily available in their home cages. The rats had previously been trained in behavioural manipulations, and thus were prepared to perform in such an experimental paradigm. To the extent that their specific histories involved an unknown number of varied manipulations, these animals were considered appropriate examples of those generally used in behavioural manipulation studies and may better replicate real-life experiences in a wide-range of contingencies.

Apparatus

Sessions were conducted in a closed laboratory with a maintained environment. Four, standard, 23.5 x 23.5 x 23.5 cm operant conditioning chambers were used. Each chamber had two levers either side of a central recessed food hopper, and light cues were mounted above each lever that, when illuminated, indicated when that lever was 'active' (or when a response on a specific lever will evoke reinforcement). When appropriate, food reinforcement was delivered to the hopper. The chambers were encased in sound-absorbing wood constructs, with further outside noise masked by a ventilating fan. Reinforcement consisted of 45-mg standard Noyes food pellets, and was delivered as described above.

Procedure

Subjects were randomly divided into three groups of eight: two experimental groups, which received either random-ratio (RR) training, or random-interval (RI) training, and one control group which, at first, received no training (None). Rats in the experimental groups received 30 sessions training on either RR or RI schedules with two sessions daily. The RR schedule value was gradually increased over the course of training as follows: Session 1, RR-5; Session 2, RR-10, Sessions 3-4, RR-15, Sessions 5-7, RR-20, Sessions 8-10, RR-25; Sessions 11-30, RR-30. Subjects in the RI group were yoked to a master subject in the RR group, and received the same frequency of reinforcement as their master animal, but delivered on an RI schedule. The same yoked and master rat

were paired throughout the study. Subjects were trained on 60 minute sessions, with two sessions per day, five days per week.

All groups were then exposed to an FI 60-s schedule for 20 sessions, with 60-minutes per session. Data were recorded in ten second 'bins' of responding for each sixty second interval.

Results

The total number of responses emitted per session, during exposure to the FI schedule, were recorded. The data from each session of FI training also were divided into ten, 6-s second 'bins' of responses. A 'bin' represents the total number of responses emitted across each 6-s period in each FI 'trial' during a session (i.e. from the delivery of the previous reinforcement until the next 60 s criterion elapsed). As such, it was possible to analyse an animal's response pattern over an entire session, and within each FI reinforcement trial. Data were further divided into 'blocks' of 5 sessions, with a total of 4 blocks of five test sessions in the experiment. All results are based on the mean block performance.

Total Response Rate

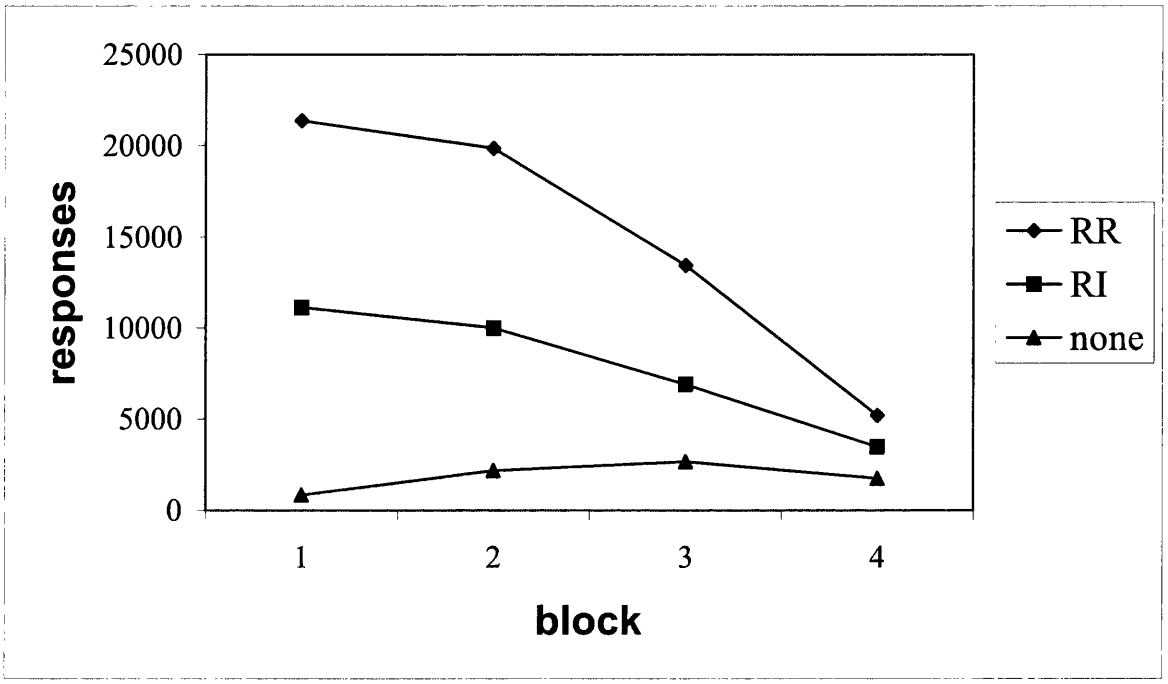

Figure 2.1 Number of total responses emitted over four blocks for RR (history of random-ratio training), RI (history of random-interval training) and none (exposure only to fixed-interval training with no history)

Figure 2.1 shows the cumulative number of responses emitted by each group over each of the five-session blocks. Rats in the RR pre-training group initially had higher rates of response in comparison with other two groups, while rats in the no history group showed consistently lower rates of response across the blocks. By the end of training, these differences appeared to be largely negated, with both RI and RR pre-training groups showing substantially lowered numbers of responses for the duration of the interval.

A two-factor mixed-model analysis of variance (ANOVA) was conducted on the total responses emitted, with schedule as a between-subjects factor, and

block as a within-subject factor. This analysis demonstrated a statistically significant main effect of block ($F(3,63) = 19.99$, $p < .001$), and schedule ($F(2,21) = 160.83$, $p < .001$). A statistically significant interaction effect of schedule and block was also present ($F(6,63) = 7.98$, $p < .001$). To further analyse these data simple effect analyses for schedule on each block were conducted. A statistically significant effect of schedule on total responses was found for block 1 ($F(2,63) = 7.91$, $p < .05$), and block 2 ($F(2,63) = 5.52$, $p < .05$), other ps $> .1$. Tukey's Honestly Significant Difference (HSD) tests were conducted for blocks 1 and 2. These tests revealed that RR totals were significantly higher than both RI and no history totals, and RI showed significantly higher response totals than no history, all ps < 0.05.

Within-Session Responding

Figures 2.2 through 2.5 show the number of responses emitted in each six-second bin of the FI 60 schedule for each successive five-session block of training.

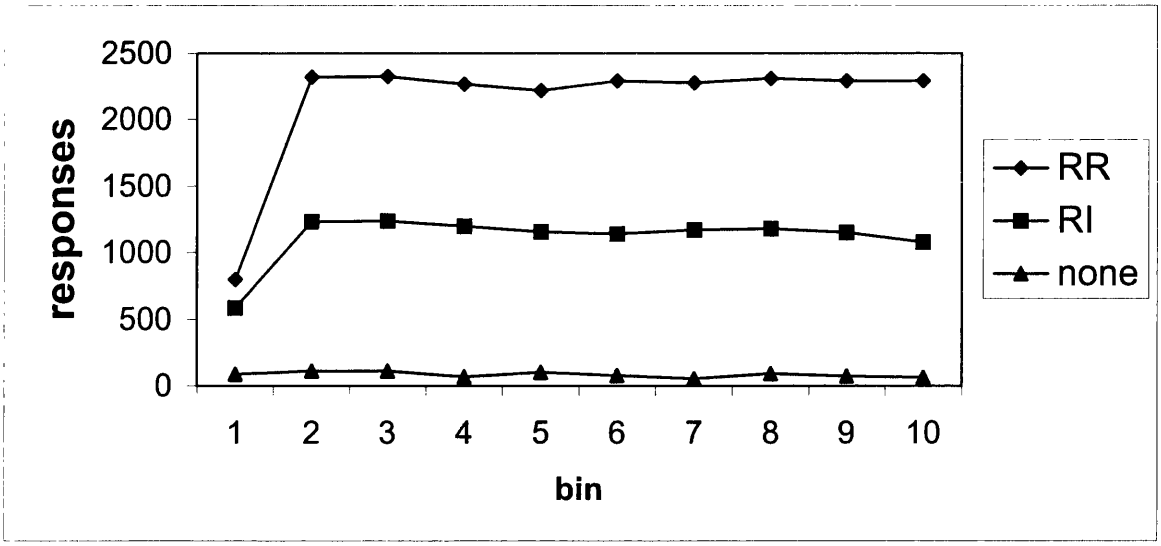

Figure 2.2 Block 1 (sessions 1-5) total responses over ten six-second bins for RR (history of random-ratio training), RI (history of random-interval training) and none (exposure only to fixed-interval training with no history)

Inspection of performance over the first block (sessions 1-5) shows the mean performance over the first 5-sessions of training, with little evidence of scalloping for any group (Figure 2.2). In initial sessions, an overall high and sustained rate of response can be seen particularly in the RR group, and to some degree in the RI group, with the no history control group showing extremely low overall rates of response in the first five-session block. Both the RR and RI rats show some evidence of a post-reinforcement pause (as shown by initially low rates 'spiking' after the first six second bin), which does not appear to be present in the no history rats.

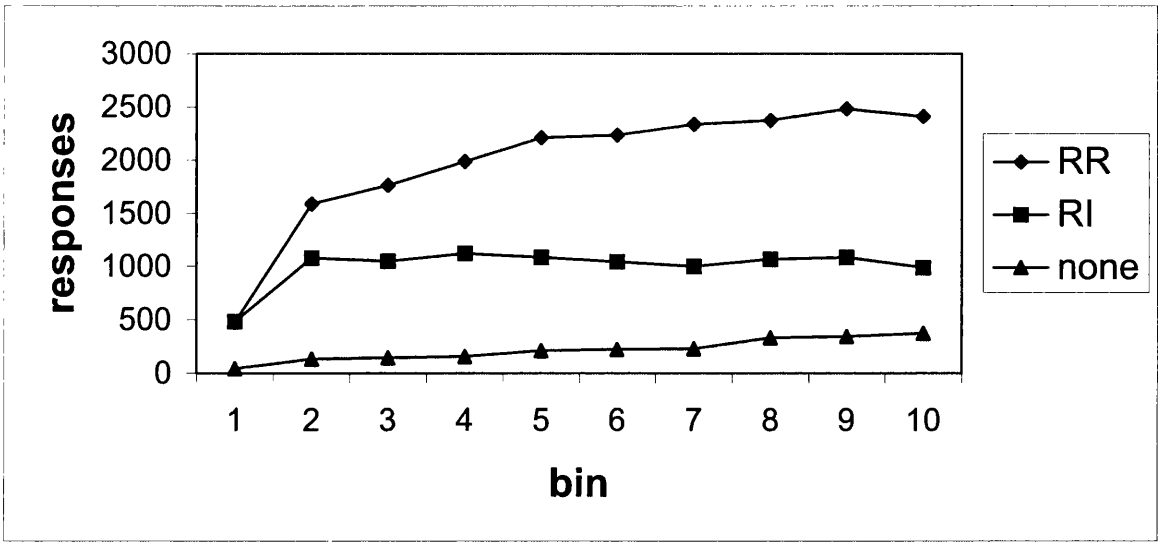

Figure 2.3 Block two (sessions 6-10) total responses over ten six-second bins for RR (history of random-ratio training), RI (history of random-interval training) and FI none (exposure only to fixed-interval training with no history)

The second block of training shows little change in the response patterning emitted by the RI rats, and some degree of increasing response rate, traditional in scalloping, for the RR group, although it is not characterised by an overly pronounced low rate of response initially. No history rats show overall low rates of response, although have begun to show slowly increasing rates with each successive, bin as is characteristic of the scalloping pattern. Despite these changes, RR pre-trained rats continue to show much higher rates of response when compared to other groups, with no history rats showing the lowest response rate over time (Figure 2.3).

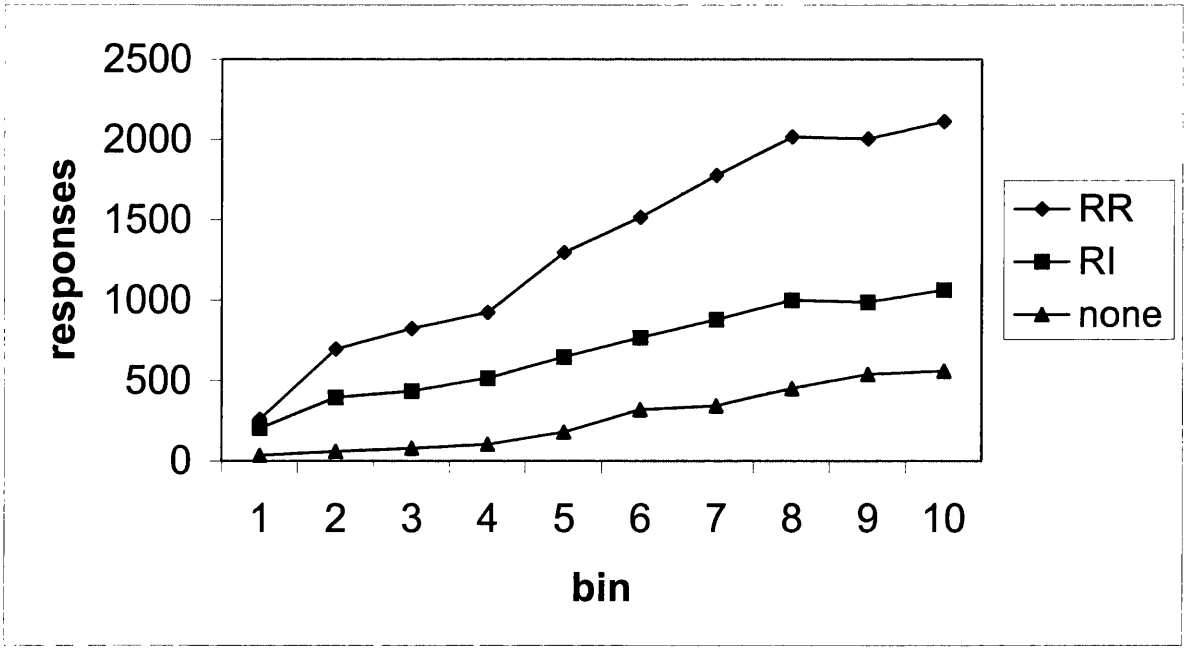

Figure 2.4 Block three (sessions 11-15) total responses over ten six-second bins for RR (history of random-ratio training), RI (history of random-interval training) and none (exposure only to fixed-interval training with no history)

Figure 2.4 shows responses over time for the third block of five-sessions on fixed-interval training. Lower initial rates, followed by slowly increasing rates of response, can now be seen for all groups, although only the no history group shows what appears to slight scalloping in the first six bins (36 seconds). The no history rats have begun to show clear evidence of scalloping, and particularly in the initial section of training. Extremely low initial rates (in the first 6 second bin) can be seen in all groups, indicating the presence of a post-reinforcement pause in response behaviour.

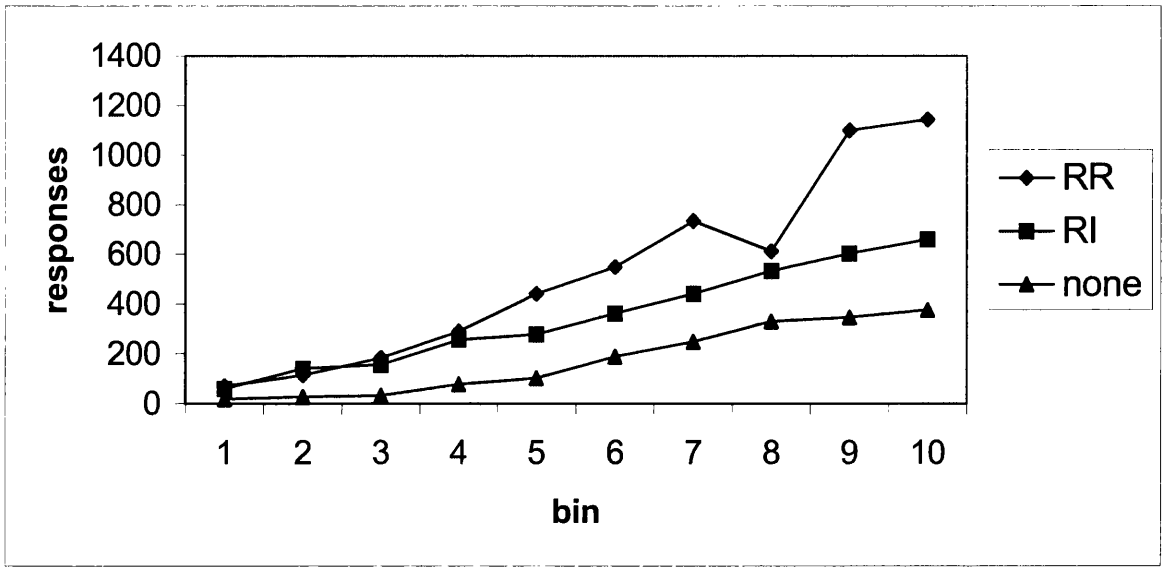

Figure 2.5 Block four (sessions 16-20) total responses over ten six-second bins for RR (history of random-ratio training), RI (history of random-interval training) and none (exposure only to fixed-interval training with no history)

By the final five sessions, all groups show evidence of the scalloping pattern characteristic of fixed-interval training. Over time, RR rats seemed to show the most erratic patterns, and have the least clear scalloping response with an odd dip in responses at bin 8 (42 seconds). RR rats continue to show heightened numbers of responses overall, followed by RI and with lowest overall rates emitted by the no history group despite a consistent rate of reinforcement across groups (Figure 2.5). Although an anomaly does appear in bin 8 of this block, this was not characteristic of all rats in this group.

To analyse the data shown in Figure 2.1 to 2.4, a three-way mixed-model ANOVA (schedule x block x bin) was conducted. This analysis revealed statistically significant results for the main effect of block ($F(3,57) = 19.99$, $p < .001$), the main effect of bin ($F(9,171) = 46.96$, $p < .001$), and the main effect of

schedule ($F(2,19)= 160.00$, $p < .001$). Statistically significant interaction effects were also noted between schedule and bin ($F(6,171) =10.92$, $p < .001$), block and bin ($F(18,513) = 10.92$, $p < .001$), and block, bin and schedule ($F(27,513) = 14.69$, $p < .001$). No other interaction effects proved to be statistically significant, all ps > 0.1.

To further analyse the three-way interaction, a series of two-way ANOVAs (bin x schedule) were performed on blocks 1-4 individually (as recommended by Howell, 1998). For block 1, a statistically significant main effect of bin ($F(9,189) = 69.12$, $p < .001$), and schedule ($F(2,21) = 156.47$, $p < .001$), and a statistically significant interaction ($F(18,189) = 27.89$, $p < .001$), were noted. To further analyse the interaction, one-way ANOVAs were carried out for the effect of schedule on each individual bin (using a Bonferroni correction to reduce the chance of type 1 error, that is, a rejection criterion of $p < .005$ was adopted). There were statistically significant differences between schedules on all bins (all ps $< .001$), with significant differences between all schedules for all bins on follow-up Tukey's HSD ($p < .005$), with the exception of between RR and RI schedules at bin 1 ($p = .312$).

The two-way ANOVA (schedule x bin) for block 2 showed statistically significant main effects of bin ($F(9,189) = 36.69$, $p < .001$), and schedule ($F(2,21) = 99.28$, $p < .001$), and a statistically significant interaction between the two factors ($F(18,189) = 13.25$, $p < .001$). Follow-up one-way ANOVAs for schedule on each bin revealed a significant effect of schedule on all bins (all ps $< .001$). Tukey's HSD tests revealed significant differences for all schedules on all bins (all ps < 0.005), excluding the following: RR and RI on bin 1 ($p = .994$), bin 2 ($p =$

.099), bin 3 (p = .052), and bin 4 (p =.030); RI and no history on bin (p = .008), bin 5 (p = .016) bin 6 (p = .057), bin 7 (p = .065), bin 8 (p = .055), bin 9 (p =.038), and bin 10 (p = .063).

For block 3, there were statistically significant main effects of bin ($F(9,189) = 37.96$, $p < .001$), and schedule ($F(2,21) = 55.03$, $p < .001$), and a statistically significant interaction between bin and schedule ($F(18,189) = 5.52$, $p < .001$). To analyse the interaction, follow-up one-way ANOVAs for schedule on each bin revealed a significant effect of schedule in bin 3 ($p < .01$). Tukey's HSD conducted on bin 3 revealed significant differences between RR and no history rats ($p < .005$).

Block 4 showed only main statistically significant effects of bin ($F(18,189) = 14.29$, $p < .001$), and schedule ($F(2,21) = 21.037$, $p < .001$), but there was no statistically significant interaction ($p > .05$).

Percentage Responses

The rates of response emitted in each bin during a block of training were transformed into percentages of the overall responses emitted for the duration of that block. When displayed this allows easier comparison of the relative number of responses emitted across a session in the groups as it removes the difference in overall response rate. Figures 2.6 through 2.9 reflect these data.

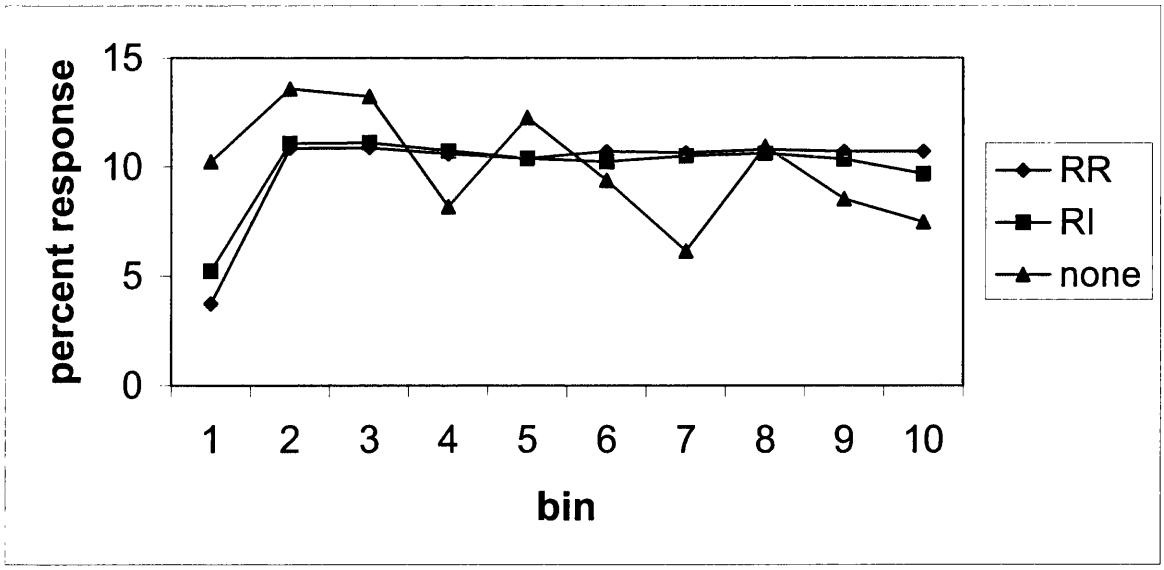

Figure 2.6 Block one (sessions 1-5) percentage of response over ten six-second bins for RR (history of random-ratio training), RI (history of random-interval training) and none (exposure only to fixed-interval training with no history)

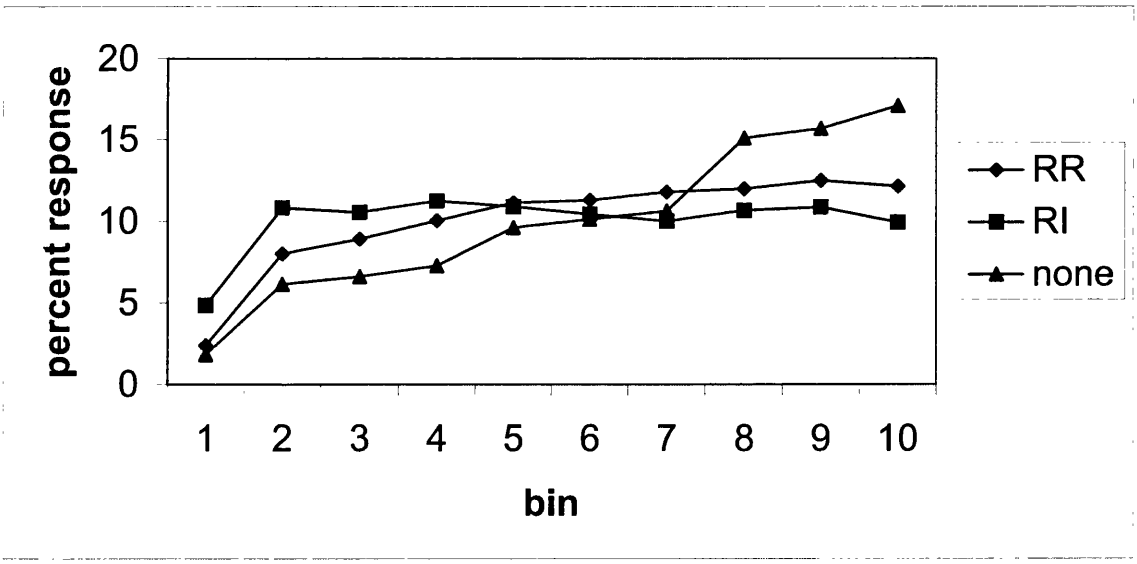

Figure 2.6. Block two (sessions 6-10) percentage of response over ten six-second for RR (history of random-ratio training), RI (history of random-interval training) and none (exposure only to fixed-interval training with no history)

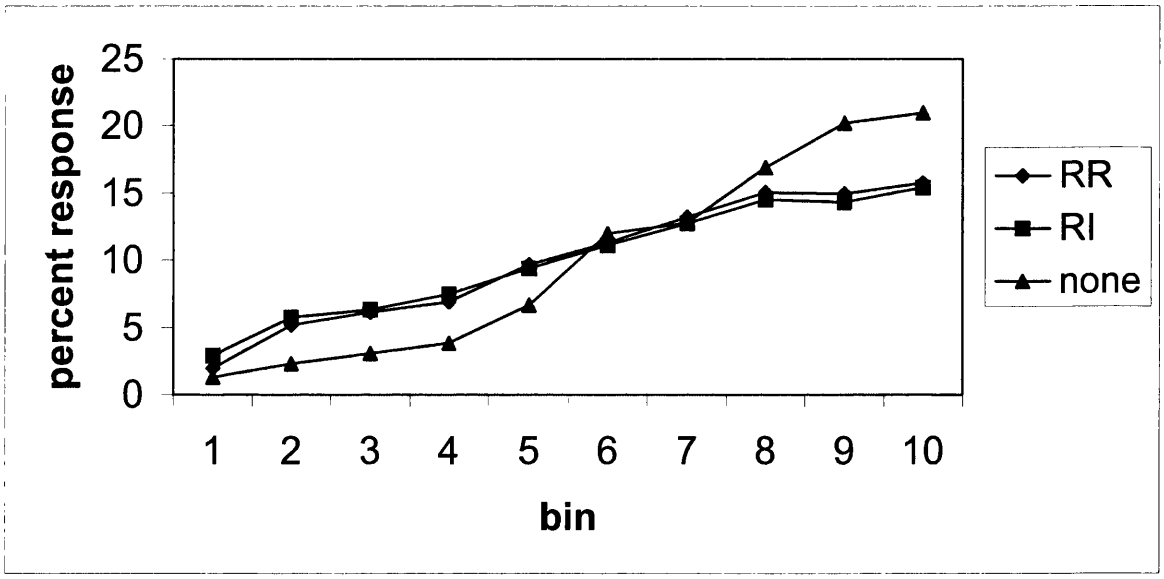

Figure 2.7. Block three (sessions 11-16) percentage of response over ten six-second for RR (history of random-ratio training), RI (history of random-interval training) and none (exposure only to fixed-interval training with no history)

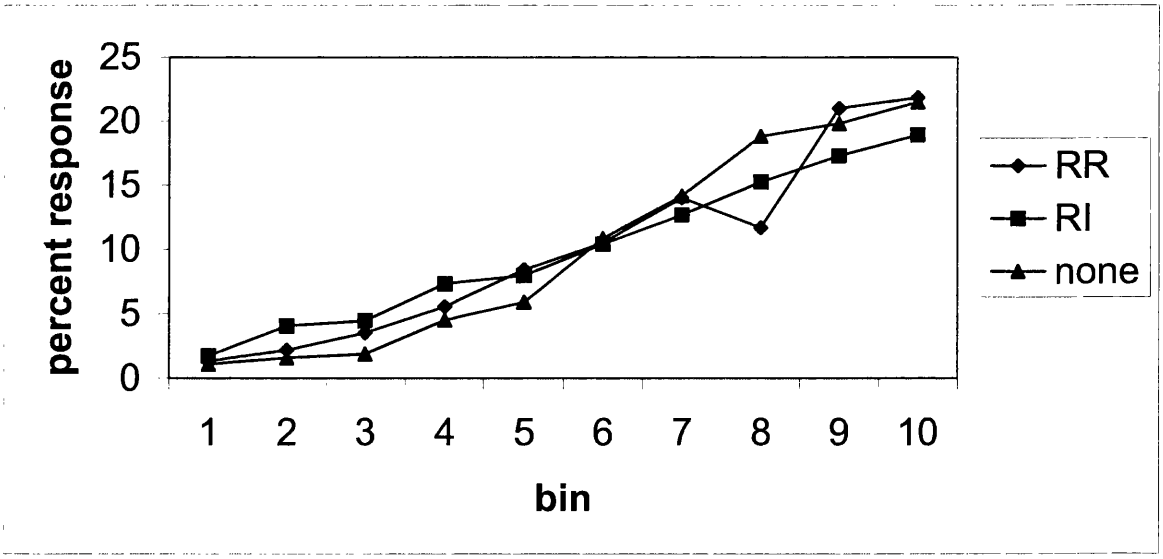

Figure 2.8. Block 4 (sessions 16-20) percentage of response over ten six-second bins for RR (history of random-ratio training), RI (history of random-interval training) and none (exposure only to fixed-interval training with no history)

Inspection of these data from the first block (sessions 1-5) shows a disorganised pattern of responses for the no history rats, varying from six to fourteen percent across the bins, and changing erratically throughout the sessions (see Figure 2.6). At this stage, no history rats also appear to emit greater percentages of responses just after reinforcement, or in the first bin, that either the RR or RI groups. A small difference also exists between the RR and RI group for the first bin in block one (see Figure 2.6), with RI rats emitting more responses that RR rats. After this point, the groups appear highly similar.

The erratic pattern of responses across the bins exhibited by no history rats seems to have levelled out by block 2 (see Figure 2.6), where the beginnings of scalloping can be seen in initially low percentages of response occurring in the first bins, followed by increasing percentages and peaking in the final bin. Again, the RI group shows the least evidence of developing a post-reinforcement pause, as demonstrated by a relatively higher number of responses emitted in the first bin that the RR and no history groups (which show similar performance in bin 1 or this block).

The more typical 'scalloping' pattern becomes clearer in the third (Figure 2.7), and fourth (Figure 2.8), blocks. Where before it was seen that no history rats showed overall lower numbers of responses in the final bin (Figure 2.4), here it can be seen that the larger percentage of responses across the trial was displayed by the no history rats as compared to their RR and RI counterparts (Figure 2.8). In contrast, both RR and RI rats show a similar pattern of response percentages to each other. By the final block, all groups show clear evidence of scalloping

percentages, with the strongest appearing to be in the no history group although it is clear that training is converging on this norm (Figure 2.8).

A three-way mixed-model ANOVA (schedule x bin x block) was conducted, with schedule as the between-subjects variable, and block and bin as within-subject variables. This analysis revealed a statistically significant main effect for bin ($F(9,171) = 109.87$, $p < .001$), and for the interactions between bin and schedule ($F(18,171) = 3.363$, $p < .001$), block and bin ($F(27,513 = 30.43$, $p < .001$), and between all three factors ($F(54,513) = 4.52$, $p < .001$).

To further analyse the three-way interaction, separate two-factor ANOVAs (schedule x bin) were conducted on the percentage scores for each block. These analyses revealed a statistically significant main effect of bin ($F(9,189) = 2.94$, $p < .001$), as well as a statistically significant interaction between schedule and bin ($F(18,189) = 5.36$, $p < .001$) for block 1. The same pattern of results was noted for block 2 (bin: $F(9,189) = 39.46$, $p < .001$; interaction: $F(18,189) = 6.20$, $p < .001$); and also for block 3 (bin: $F(9,189) = 136.71$, $p < .001$; interaction: $F(18,189) = 4.87$, $p < .001$). Block 4 showed only a statistically significant main effect of bin ($F(9,189) = 92.01$, $p < .001$). All other main effects and interactions were not statistically significant, all ps > .1.

One way ANOVAs (with Bonferroni correction, as described above; new rejection criteria is $p < .005$) were conducted on the effect of schedule on each bin for the blocks that displayed a statistically significant interaction between schedule and bin (i.e. blocks 1, 2, and 3). These analyses showed significant effects of schedule in block 1 for: bin 1 ($F(2,21) = 11.28$, $p < .001$), bin 4 ($F(2,21) = 12.81$, $p < .001$), bin 9 ($F(1,21) = 11.02$, $p = .001$) and bin 10 ($F(1,21) = 10.55$, $p = .001$).

Tukey's HSD for these results show a significant difference between RR and no history, and between RI and no history for all significant bins (1, 4, 9 and 10; p <.0125).

In block 2, bins 1 ($F(1,21)=7.11$, p =.005), 3 ($F(1,21)=8.76$, p <.005), 4 ($F(1,21)=14.63$, p <.001), 7 ($F(1,21)=13.52$, p <.001) and 10 ($F(1,21)=15.02$, p <.001). HSD results showed significant differences between RI and no history at all significant bins (p <.005), with no significant differences between RR and RI or between RR and no history.

Block three only showed a significant effect of schedule on percent at bin 9 ($F(1,21) = 41.51$, p<.001), with significant Tukey's results between RR and no history. No significant results were reported for block 4 for effect of schedule on any individual bin.

Index of Curvature

The index of curvature (Fry, Kelleher & Cook, 1960) is a statistic that shows the extent to which responding is distributed through the interval, with an even distribution occurring at 0, and a distribution condensed in the final bin taking a value of .999. The higher the index of curvature, the sharper the scalloping, and the higher the concentration of responses in later bins of the curve. A negative index of curvature indicates that as the curve increases, the rate of response decreases and will show an inverse scalloping pattern on a graph. However, it should be noted that this measure is not sensitive to time, in that it does not account for the positioning of response within a bin, and is only a value representative of response rate (see Payla & Bevins, 1990).

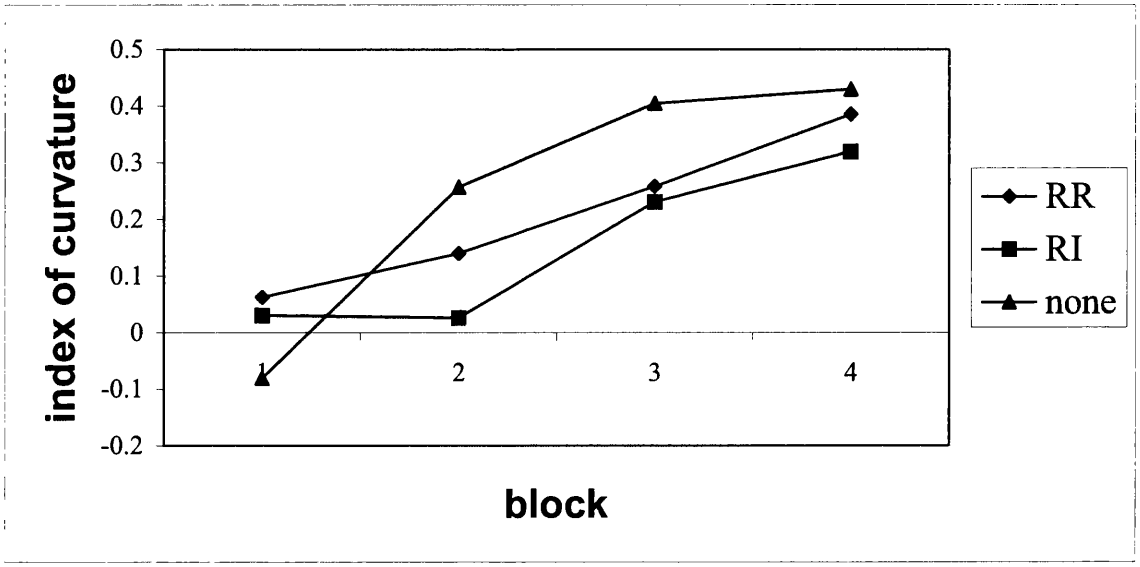

Figure 2.9 Index of curvature values for blocks 1-4 for RR (history of random-ratio training), RI (history of random-interval training) and none (exposure only to fixed-interval training with no history)

Figure 2.9 shows the index of curvature values for the cumulative responses of the RR, RI and no history groups. The no history rats initially showed a mild, negative index, that rapidly increased in the second block, and peaked in the final blocks, showing a moderate scalloping curve of .43. The RR and RI groups both showed initial low rates for the index of curvature, with rates below .1, and nearing zero indicating a relatively consistent rate of response in the initial sessions. For the RR group, the index of curvature steadily increased with each successive block, eventually nearly reaching that of the no history group. The RI group shows an index of curvature that actually appears to decrease slightly in the second block, before increasing in the third to reflect a curve similar to that of the RR rats.

A two-way mixed-model ANOVA (block x schedule) was conducted on the index of curvature scores. This analysis revealed a statistically significant main effect of block ($F(3,63) = 101.24$, $p < .001$), and schedule ($F(2,21) = 232.84$, $p < .001$), and a statistically significant interaction between block and schedule ($F(6,63) = 13.19$, $p < .001$). To further analyse these data separate one-way ANOVAs for the effect of schedule on each blocks were then carried out, using a Bonferroni correction for multiple tests, with the new significance level set at $p < .0125$. These analyses revealed a statistically significant effect of schedule on index of curvature reported for block 1 ($F(2,21) = 14.32$, $p < .001$), with Tukey's HSD results showing significant differences between RR and no history, and between RI and no history ($p < .0125$). For block 2, there was a statistically significant effect of schedule ($F(2,21) = 22.74$, $p < .001$). Follow-up Tukey's showed a significant difference only between RI and no history group ($p < .0125$). The ANOVA for block 3 revealed a statistically significant effect of schedule ($F(2,21) = 7.97$, $p < .001$), with Tukey's HSD showing significant results for both RI and RR when compared to the no history group ($p < .001$). There was no statistically significant effect of schedule for block 4 ($p > .20$).

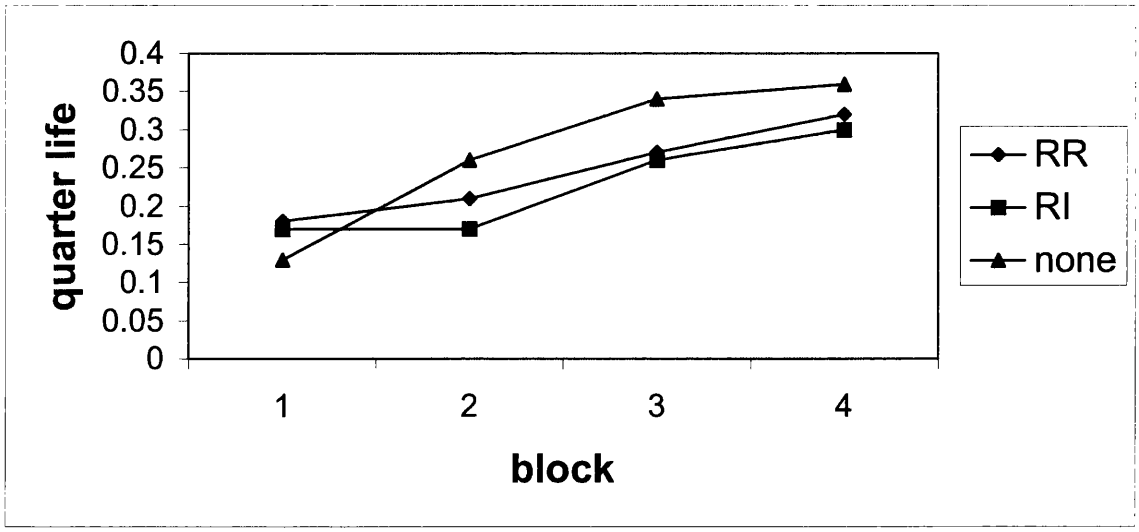

Figure 2.10 Quarter life values for blocks 1-4 for RR (history of random-ratio training), RI (history of random-interval training) and none (exposure only to fixed-interval training with no history)

Figure 2.10 shows the quarter lives (Hernstein & Morse, 1957) for each of four five-session bins on FI performance. Quarter life can be defined as the amount of time passed in the set interval at which 25% of responses have been emitted. As such, this value will be .25 (25%) if the rat has emitted a steady rate of response throughout the interval (25% or responses emitted at 25% of the interval). However, as the current sessions are set at 60 seconds, the value of the quarter life at which a steady response throughout the interval can be seen is .15 (or, one quarter of the time through the interval), rather than .25. If the rat is showing an FI specific curve, it is expected that the quarter life value will be higher than 15% as fewer responses are made in the initial bins of the session, and responses become concentrated in the latter portion of the interval (Baron &

Leinenweber, 1995; Cole, 2001). Figures lower than .15 indicate higher numbers of responses being made in the initial bins of the trial.

The quarter life was calculated by first determining the number of responses at which one quarter of responses had occurred, and then assuming a linear relationship between the two bins bracketing that number. A line was then be fitted to those points, and the quarter life was determined based on the equation for that line. Note that this does not assume a linear relationship for the entire curve, but only for the small region between two points. As a result there is some margin of error in this number, as it's possible that rats did not respond linearly within each bin.

Figure 2.10 shows cumulative quarter-life numbers for blocks 1-4, with moderate skewing occurring for all groups by the final block, and no history rats developing higher numbers sooner than either the RI and RR groups and the RI group showing no change from block 1 to 2. No history rats clearly showing an increase in quarter life values and the highest terminal value, followed by RR and RI rats respectively.

A two-factor mixed-model ANOVA (schedule x block) was conducted on these quarter life scores. The results showed statistically significant main effects of block ($F(3,63) = 3.58$ $p < .05$), and schedule ($F(2,21) = 19.07$, $p < .001$), and a statistically significant interaction between block and schedule ($F(6,63) = 3.79$, $p < .01$). As described above for the Index of Curvature, one-way ANOVA follow-ups conducted for schedule on each block revealed a significant effect of schedule (defined as $p < .0125$) for block 1 ($F(2,21) = 6.82$, $p < .01$), block 2 ($F(2,21) = 11.94$, $p < .001$), and block 3 ($F(2,21) = 16.42$, $p < .001$), but not for block 4 ($p >$

.178). Tukey's HSD tests were conducted on the data where the one-way ANOVAs showed significant differences (i.e. blocks 1, 2 and 3). These showed significant differences for block one between RR and no history ($p < .0125$), but not between RI and no history; for block two only between the RI and no history groups ($p < .0125$); and for block three for both RI and RR when compared to the no history group ($p < .001$). There was no statistically significant effect of schedule for block 4 ($p > .20$). Because quarter life is a statistic representing response pattern throughout the session, these results are highly reflective of those from the index of curvature statistic.

Discussion

The present data indicates that there is some relationship between historical training and present performance on a fixed-interval schedule. Terminal baseline response rate and rate of reinforcement prior to the manipulation were comparable across groups, and do not provide sufficient evidence for causation of these difference. However, as in previous research (e.g., Baron & Leinenweber, 1995; Cole, 2001; Lopez & Menez, 2005) this effect seems to be transitory, especially in the context of overall rates of responding and response patterning. In the current study, the effect of history of training peaked during sessions 6-10, and slowly lost an effect over the remaining sessions. There does not seem to be evidence supporting a permanent effect of either RR or RI schedules on FI performance, contrasting those effects found by Wanchisen et al .(1989). By the final sessions, rates of response were developing the scalloping expected of fixed-interval performance, irrespective of prior training, and by the third block of training there

were no significant difference of response rate for the history groups when compared to a control sample. These results particularly reflect that of Lopez and Menez (2005) who found that effects of previous conditioning histories tended to erode with time exposed to fixed-interval continuums.

Although there were no lasting effects of the history training, the data from the percentage responses emitted did illuminate some interesting effects of prior training on FI performance. That is, rats exposed to RI schedules of reinforcement took longer to show scalloping like effects, than those exposed to RR schedules of reinforcement. This difference could not be due to differences in reinforcement rate, and these two schedules were yoked in this respect. The lack of a very strong effect of previous RR training contrasts with predictions made by Wanchisen et al., (1989). The sustained history effect reported by Wanchisen et al. (1989) was evident in rats trained on an A-B-A-B design, alternating VR training with FI training, that never developed traditional scalloping generally seen in FI performance, and as demonstrated by an FI only control group. It is possible that these results reported by Wanchisen et al., (1989) would have eventually converged on results similar to those reported in the present study. The authors did report some movement towards traditional FI responses, but as analysis did not include either index of curvature or quarter life results this movement is anecdotal.

However, the current results showing a difference between prior exposure to an RR and an RI schedule do reflect the findings reported by Cole (2001). In this latter study, historical training on schedules resulting in low response rates (DRL), and high response rates (FR), showed significantly different performance on subsequent FI contingencies, primarily in initial sessions where response rates

for FR rats decreased as those for DRL rats increased to converge on normal FI responding. Cole (2001) also reports a lower response rate between rats exposed to DRL schedule as compared those exposed to FR schedules, a finding mirrored by current results where RI pretraining resulted in significantly lower response rates than did RR pretraining. However, rats trained in FR and DRL schedules showed sustained, significantly lower rates of response in Cole's sample, an effect that was not reproduced by the current research. Further, Cole required 80 sessions of FI training to acquire nonsignificant differences between groups, whereas the present research shows nearly identical response patterns after only 20 sessions of FI training. Although it can also be noted that Cole's procedure used at least 55 sessions of training whereas the current study utilized only 30, comparable rates of response were achieved for both procedures. Despite this, duration of training may be a variable of interest in future research, as it could at least partially explain differences in persistence of differences between groups.

Although quarter life and index of curvature data has only intermittedly been reported in studies of FI scalloping, this data provides particularly rich insight into the interaction of schedule on response independent of response rate. Both of these measures demonstrate a strong effect of schedule on response pattern in initial sessions. In particular, it was seen that rats exposed to a an RI schedule took longer to show performance typical of rats only exposed to an FI schedule, when compared to the performance of rats exposed to an RR schedule. There are many potential explanations for this effect, but these will be discussed later, pending the replication of this effect.

In summary, the current results presents evidence that simple RR and RI historical contingencies can manifest in significantly different patterns and rates of response on later FI response. Although these effects are transitory, and while similar to some studies (e.g., Cole, 2001), are not those predicted in the seminal work in the area (see Wanchisen et al., 1989; Weiner 1964). Further, the use of non-experimentally naïve rats provides some context of the behavioural history characteristic of humans; despite this, no lasting effect of this variable history was found. Although this behavioural history could be viewed as a confound, if these data are replicable in an experimentally naïve sample stronger evidence will be present for this pattern of response in a rat population (as compared to humans). Additional research could also demonstrate this effect within rather than between subjects, which would control for individual differences in subject performance and further support the effects delineated above.

Chapter 3: Within-subject effects of RR and RI histories on subsequent FI performance

Most accounts of the effect of reinforcement contingencies dictate an almost complete focus on current contingencies over historical ones (e.g., Ferster & Skinner, 1957). Under this approach, previous contingencies would be viewed as comparatively irrelevant, because the effects of past learning will eventually subside. As noted in previous chapters, there are experimental demonstrations of such an effect (e.g., Baron & Leinweber, 1995; Freeman & Lattal, 1992), in which organisms with highly regimented reinforcement histories nonetheless show nearly identical performances following sufficient training on new contingencies. Although these studies present some evidence that current contingencies will eventually appear to override historical ones, it is not sufficient evidence that the historical contingencies have no affect on this process. In fact, previous training has been shown to have some interaction with the development of response to a new contingency in both humans (Hojo & Ono, 2004; Mechner & Jones, 2003; Okouchi, 2003b; Weiner, 1964, 1969), and non-humans (Baron & Leinenweber, 1995; Freeman & Lattal, 1992; Nader & Thompson, 1987; Okouchi, 2003b; Wanchisen, Tatham & Mooney, 1989).

The experiment presented in Chapter 2 provides further evidence for the transitory presence of history effects, and particularly for the differential presence of these effects between different schedules when reinforcement rates within trials have been controlled for using the yoking procedure. However, given the limited and conflicting nature of current research in this area, replication of the

phenomena observed in Chapter 2, using similar conditions, would be appropriate. The difficulty of subsequent studies to demonstrate the striking results reported by Wanchisen et al. (1998), where the effects of RR pretraining appeared to persist indefinitely, pose compelling reasons to confirm results found in the previous study, which do not show such strong and long-lasting effects.

Further, while the previous study reported in Chapter 2 showed an effect of pretraining using a between subjects procedure, it is possible that a within-subjects procedure may produce different results. Church (1966) has pointed out that yoking between-subjects engenders the possibility of response rate differences being introduced due to individual differences in sensitivity to reinforcement. It may be that the effects of training history on current performance may be more consistently demonstrable within-subject, as within subject designs remove subject variance (used to test treatment effects), and are more statistically robust to differences between individual animals (Greenwald, 1976). These possibilities may impact on the results obtained in the study of history training on current FI performance. Systematic replication of the results obtained in Chapter 2, using a within-subject procedure, would add to the reliability of the findings.

The study described in the present chapter proposes a within-subject examination of history effects on subsequent learning, with an emphasis on fixed-interval training following exposure to random-ratio and random-interval training equated for reinforcement rate. It is expected that results will replicate those found in a between-subjects procedure (as in Chapter 2), and in Freeman and Lattal (1995), Wanchisen, Tatham & Mooney (1989), Cole (2001) and Okouchi (2003a). That is, it is expected that there will be an effect of RR training on

subsequent FI performance. Moreover, it may be that the more pronounced detrimental effect of RI training on retarding the development of FI performance will be observed within-subject. As with the between-subject procedure described in Chapter 2, these effects are posited to be transient, eventually giving way to similar performances on FI schedules regardless of prior training, and independent of response rate due to the yoked design. Further, use of the within-subjects design will present stronger evidence for the universality of this effect, and will eliminate any possible confound due to differences between groups. Prior to this, the effects of schedules with lower rates of response but equal rates of reinforcement (RI as compared to RR) have never been demonstrated using a within-subject yoked design. The present study will provide further evidence into the role of response rate independent of reinforcement rate impacts later learning processes.

Method

Subjects

Seven, male Lister hooded rats were used in the current experiment. The subjects were maintained at 85% of their free-feeding body weight for the duration of the study, with a maintained weight varying between 355-415g. They were housed in groups of three or four, and had water readily available in the environment at all times. These animals had not been previously used in any study and, thus, were experimentally naïve.

Apparatus

Sessions were conducted in a closed laboratory with a maintained environment. Four, standard, 23.5 x 23.5 x 23.5 cm operant conditioning chambers were used, identical to those used in the previous study (see Chapter 2). The chambers contained two, retractable levers with a light above each lever indicating when the lever is active (e.g., can be used to elicit a reinforcement). When appropriate, food reinforcement was delivered in a central repressed food hopper located directly between the levers. This apparatus was encased in larger, sound-absorbing wooden boxes with any outside noise masked using a ventilator fan for each box.

Procedure

All subjects were first given standard magazine training on two, twenty-minute random-time 60-second sessions, and then were taught to press a lever for food reinforcement on two 20-minute continuous reinforcement (CRF) schedules. For the first CRF session, the left lever was inserted into the chamber with the right lever retracted. For the second CRF session, the right lever was inserted into the chamber, with the left lever retracted. This ensured that the rats were capable of lever-pressing behaviour independently on either lever. Next, the rats were given two, 30-minute multiple CRF, CRF schedule sessions, during which the light above either the left or right lever was illuminated for five minutes on an alternating schedule, with an interval of 30-seconds between components (illuminations), where neither light was lit. When the light above a particular

lever was illuminated, only responses on that lever were reinforced, although both levers were inserted into the chamber for the duration of these sessions.

Using a within-subjects design, all rats were trained on a multiple RR, RI schedule. For this section of the experiment, rats were randomly divided in two groups, with one group receiving RR training on the right lever, and the second group receiving RR training on the left lever (this controlled for any side preference in the learning process). RR and RI schedules were then presented in alternate orders, with the mean interreinforcement (IRI) interval on the RR schedule setting the mean IRI for the RI schedule in the following RI component. Thus, the rate of reinforcement across the RR and RI schedules was yoked for each rat. During these sessions, both levers were presented in the operant chamber, with the active lever being cued by illumination of the light associated with that lever. Each component (signalled by the illumination of the lever light) lasted for 5-mins, and was followed by a 30-s inter component interval).

Subjects were trained in sixty-minute sessions, with the RR schedule value gradually increased over the course of training as before (see Chapter 2): Sessions 3-4, RR-5; Sessions 5-6, RR-10; Sessions 7-8, RR-15; Sessions 9-10, RR-20; Sessions 11-12, RR-25; Sessions 13-40, RR-30. Sessions were further divided into twelve components, with each component consisting of five minutes of either RI or RR training. As discussed before, RI reinforcement rate was yoked to RR reinforcement rate set by the experimenter, ensuring that each subject received the same amount of reinforcement in both RI and RR conditions. Unlike the previous study, this was modelled after a within-subjects design, wherein each rat set his own RI reinforcement level based on RR performance.

Following this training, all rats were exposed to a multiple FI 60-s, FI-60-s schedule for 20 sessions. These sessions were similar in nature to the multiple RR, RI training described above, with six, five minute component duration for each FI schedule cued by illumination of the light above the active lever. There was a 30 second interval between components.

Results

As in Chapter 2, data were divided into ten, six-second bins of responses, where each bin value represented the total number of responses emitted by the animal during that time period. This separation of data allows more precise evaluation of inter-reinforcement interval behaviour. Again, this data was further separated into four blocks of five sessions across the multiple FI, FI schedule phase. The separation of data in this manner makes it possible to analyse an animal's response pattern over an entire session as well as within each trial.

Total Response Rate

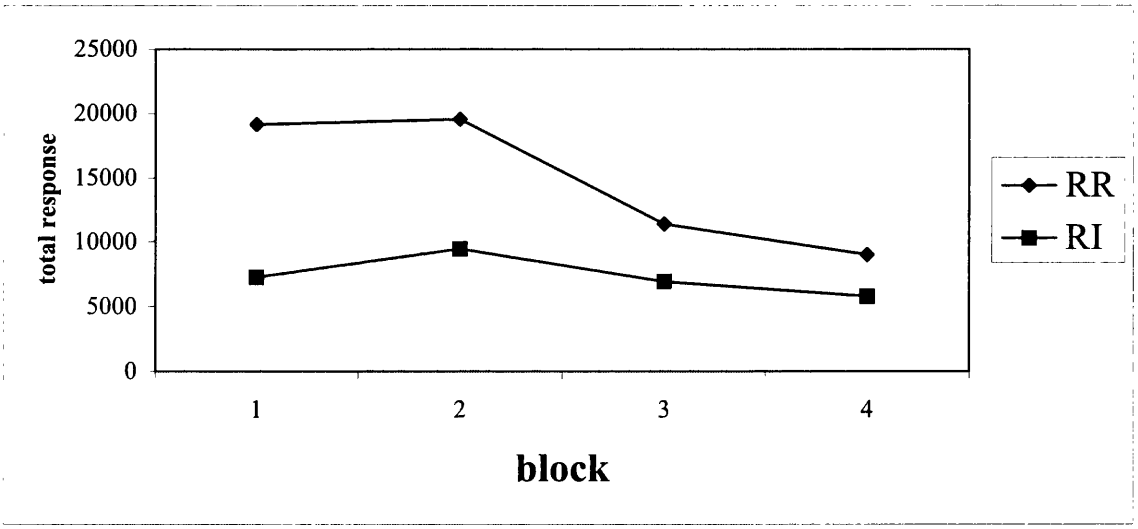

Figure 3.1 Number of total responses emitted over four blocks for RR (history of random-ratio training and RI (history of random-interval training)

Figure 3.1 shows the total number of responses emitted in the components previously associated wit the RR and RI schedules across the four, five-session blocks of multiple FI, FI training. Initially high rates are seen in component previously associated with the RR schedule for blocks 1 and 2, followed by a sharp decrease to less than half of the original response rate. Response rates in the component previously associated with the RI schedule show a more gradual decline over the course of the training.

A two-factor, repeated-measures analysis of variance (ANOVA), with schedule and block as factors, indicated statistically significant main effects of schedule ($F(1,6) = 21.25, p < .005$), and block ($F(3,18) = 21.83, p < .001$), as well as a statistically significant interaction ($F(3,18) = 11.30, p < .001$). To further analyse these data, one-way ANOVAs were carried out for the effect of schedule on total for each block (using the Bonferroni correction, $p < .0125$). The RR total responses were significantly higher for block 1 ($F(1,12) = 24.98, p < .001$), and block 2 ($F(1,12) = 8.64, p < .0125$), when compared to RI total response.

Within-Session Responding

Figures 3.2 through 3.5 show the number of responses emitted in each six-second bin of the RI and RR schedules, respectively.

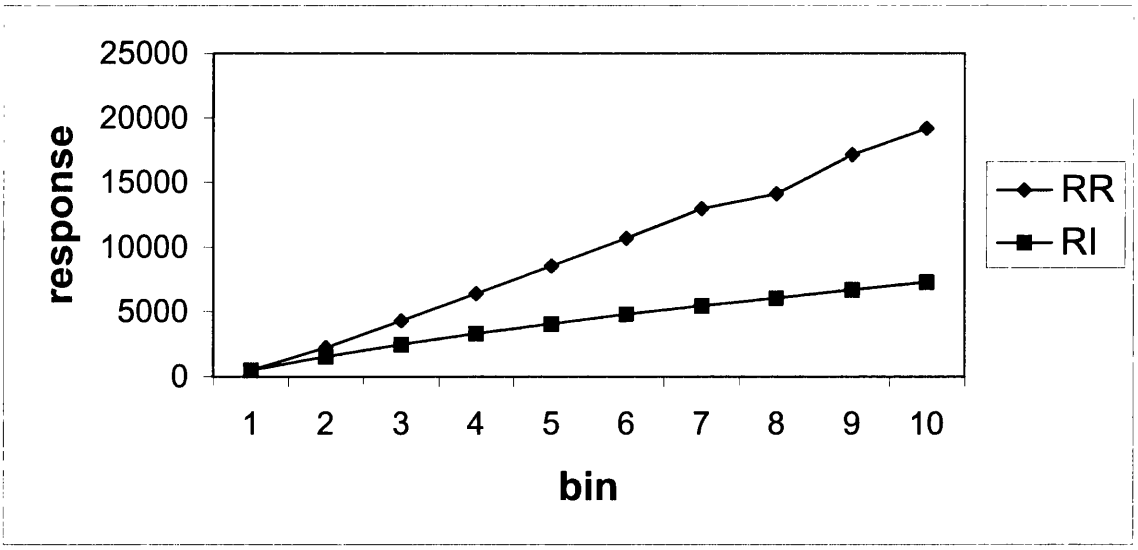

Figure 3.2 Block 1 (sessions 1-5) total responses over ten six-second bins for RR (history of random-ratio training) and RI (history of random-interval training)

Inspection of these data shown in Figure 3.2 shows little evidence of scalloping for either component in block 1, with an overall higher rate of response for the RR schedule than for the RI schedule. This reflects the cumulative data seen in Figure 3.1. Further, response rate in both schedules is slightly irregular at times, and shows no evidence of a post-reinforcement pause (usually seen by initial low rates of response followed by later high rates).

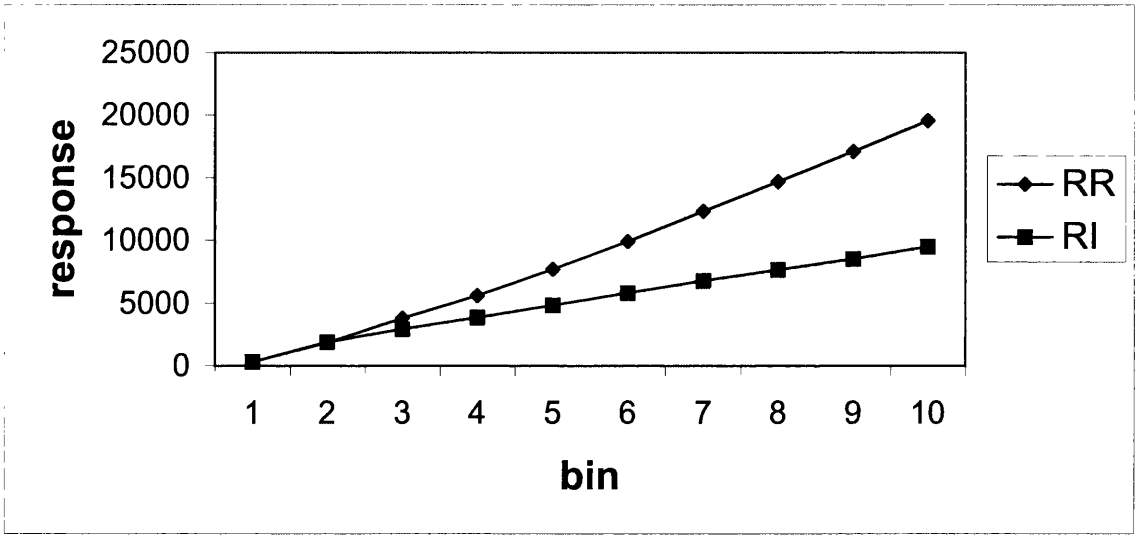

Figure 3.3 Block 2 (sessions 6-10) total responses over ten six-second bins for RR (history of random-ratio training) and RI (history of random-interval training)

Figure 3.3 shows the responses during the second block of five sessions across the ten, six second bins. As can be seen, response rate is comparatively uniform across the bins in this block, with RI response continuing to show lower rates than the RR response. Neither group manifests rates of response consistent with a post-reinforcement pause. Some evidence of scalloping can be seen in the component previously associated with the RR schedule, which does not become greater than the RI performance until the third bin (at 18 to 24 seconds into the session). This effect is very slight, however.

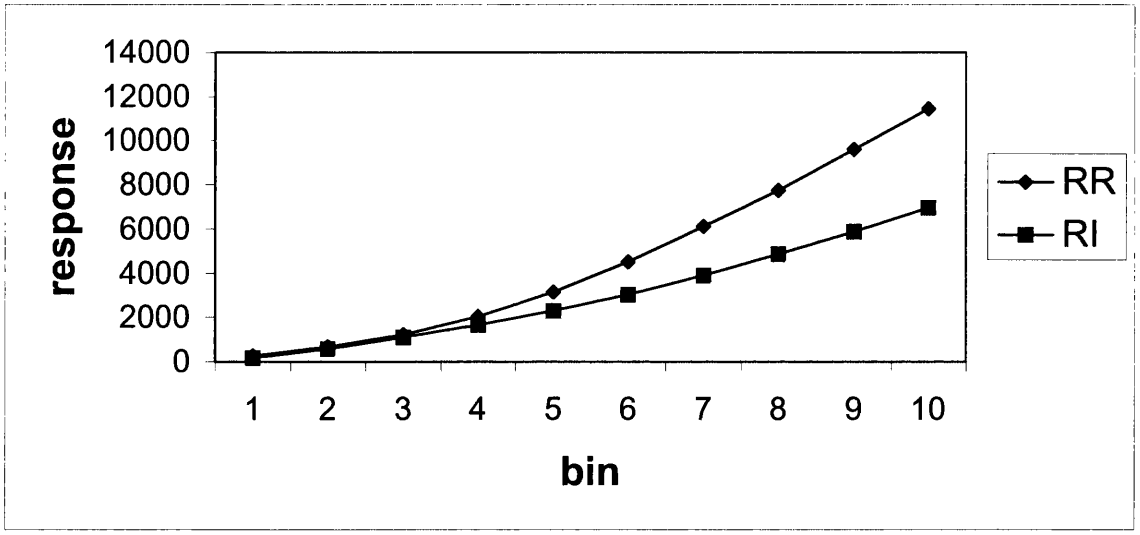

Figure 3.4 Block 3 (sessions 11-15) total responses over ten six-second bins for RR (history of random-ratio training) and RI (history of random-interval training)

Figure 3.4 shows responses over time for the third block of five sessions on FI training. Clear evidence of scalloping can now be seen in both the components previously associated with the RI and the RR pretraining, with low initial rates of response indicating some evidence of a post-reinforcement pause. Rate of responding increases with time for both groups, and differences between the groups in final rate of response (in the last bin, 54-60 seconds) clearly narrows in comparison to previous blocks.

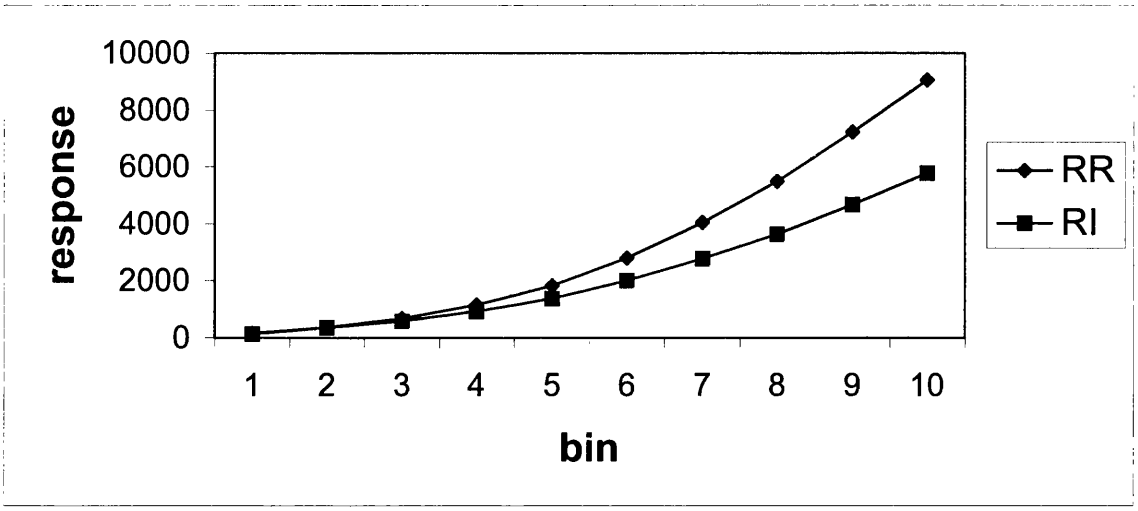

Figure 3.5 Block 4 (sessions 16-20) total responses over ten six-second bins for RR (history of random-ratio training) and RI (history of random-interval training)

Figure 3.5 shows the final five session block (4) of response on the multiple FI, FI schedule. A considerable scallop can be observed for both the components previously associated with the RR and the RI pretraining. Initially, low rates of response become increasingly higher with each subsequent bin, and differences between response rates in later bins is visibly smaller than seen in initial sessions. Although some differences between the RR and RI pretraining are still visible, the pattern of response seems similar for both response sets.

A three-way repeated-measures ANOVA (schedule x block x bin) was conducted on these data. This analysis revealed statistically significant main effects of schedule ($F(1,6) = 21.25$, $p < .005$), block ($F(3,18) = 21.83$, $p < .001$), and bin ($F(9,54) = 22.13$, $p < .001$). Statistically significant interactions between schedule and bin ($F(3,18) = 11.30$, $p < .001$), schedule and block ($F(9,54) = 9.08$, $p < .001$), block and bin ($F(27,162) = 8.21$, $p < .001$), and schedule, block and bin ($F(27,162) = 2.17$, $p < .005$) were also noted.

To follow-up the interaction of schedule, block, and bin, two-way ANOVAs evaluating the effects of schedule and bin were performed individually for each block (as per Howell, 1998). For block 1, statistically significant main effects of both schedule ($F(1,6) = 9.34$, $p < .05$), and bin ($F(9,54) = 25.22$, $p < .001$), as well as a significant interaction ($F(9,54) = 4.26$, $p < .001$) were noted. Follow-up one-way ANOVAs (using a Bonferroni correction criterion, $p < 0.005$) for the effect of schedule on each bin showed significant effects of schedule on bins 3-10, $p < .005$ for all analyses.

Analysis of data from block 2 showed a significant main effect of bin ($F(9,54) = 8.23$, $p < .001$), and a significant interaction between schedule and bin ($F(9,54) = 13.12$, $p < .001$), but not of the main effect of schedule. Follow-up one-way ANOVA for the effects of schedule on bin showed significant differences between the groups at only bin 8 ($F(1,12) = 15.16$, $p < .005$), bin 9 ($F(1,12) = 15.80$, $p < .005$), and bin 10 ($F(1,12) = 18.65$, $p < .005$).

Block 3 showed statistically significant main effects of schedule ($F(1,6) = 73.41$, $p < .001$), and bin ($F(9.54) = 19.98$, $p < .001$), with a statistically significant interaction ($F(9,54) = 6.02$, $p < .001$). One-way ANOVA results comparing the effect of schedule on each bin showed no significant differences between the schedules at the adopted criteria for rejection ($p<.005$).

Results from block 4 show a significant main effect of schedule ($F(1,6) = 7.10$, $p < .05$) and of bin ($F(9,54) = 3.85$, $p <.001$). A statistically significant interaction was also present ($F(9,54) = 5.48$, $p <.001$). As for block 3, no effects of schedule were found for any individual bin.

Percentage Responses

Figures 3.6 through 3.9 show response rate transformed into percentage of responses occurring in each bin across each block. This measure demonstrates the transience of the history effects, as it controls for response rate differences seen in previous analyses.

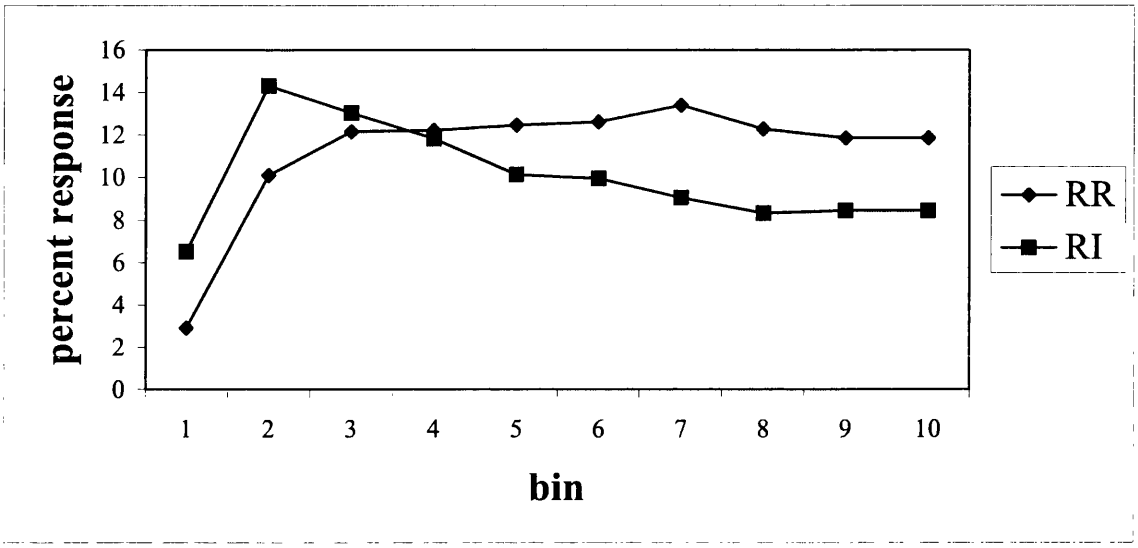

Figure 3.6 Block 1 (sessions 1-5) total responses over ten six-second bins for RR (history of random-ratio training) and RI (history of random-interval training)

Data from the first block (Figure 3.6) shows a somewhat disorganised pattern of percentages for both groups, with initially low percentages occurring in the first bin followed by an immediate spike in bin 2. This then levels out to more consistent rate for the RR response set, and to a steadily declining rate for the RI response set.

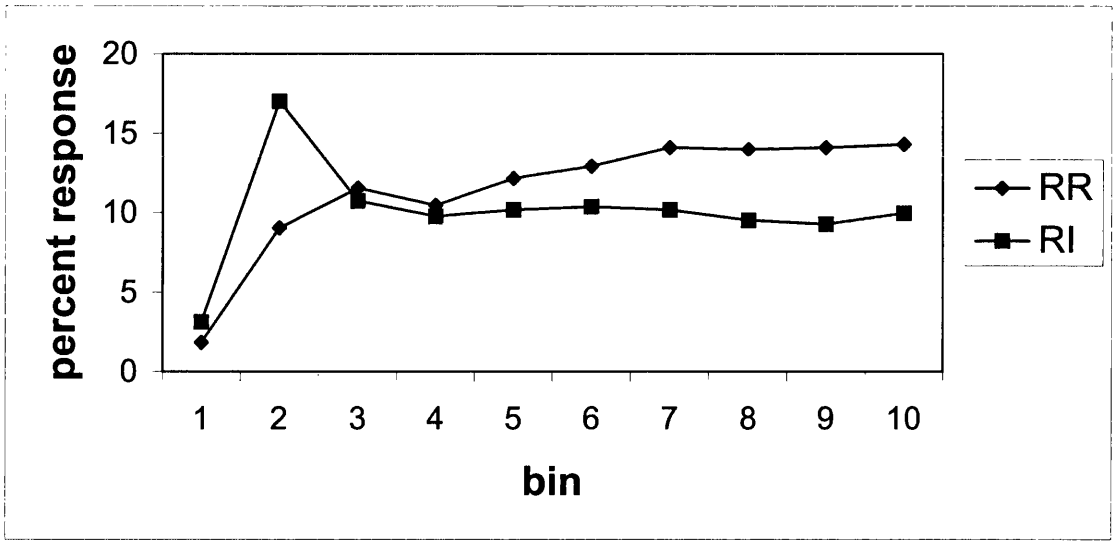

Figure 3.7 Block 2 (sessions 6-10) total responses over ten six-second bins for RR (history of random-ratio training) and RI (history of random-interval training)

A similar pattern can be seen in block 2 (Figure 3.7), with an initially low response percentage in bin 1 followed by a spike for bin 2. However, this spike is significantly larger for the component previously associated with the RI schedule than for the RR component. Further, in the latter, the spike is followed by a roughly continuous climb in increasing percentages with each successive bin. The RI component does not show this pattern, instead decreasing sharply in bin 3, and maintaining a steady percentage of responses across bins to the end of the session.

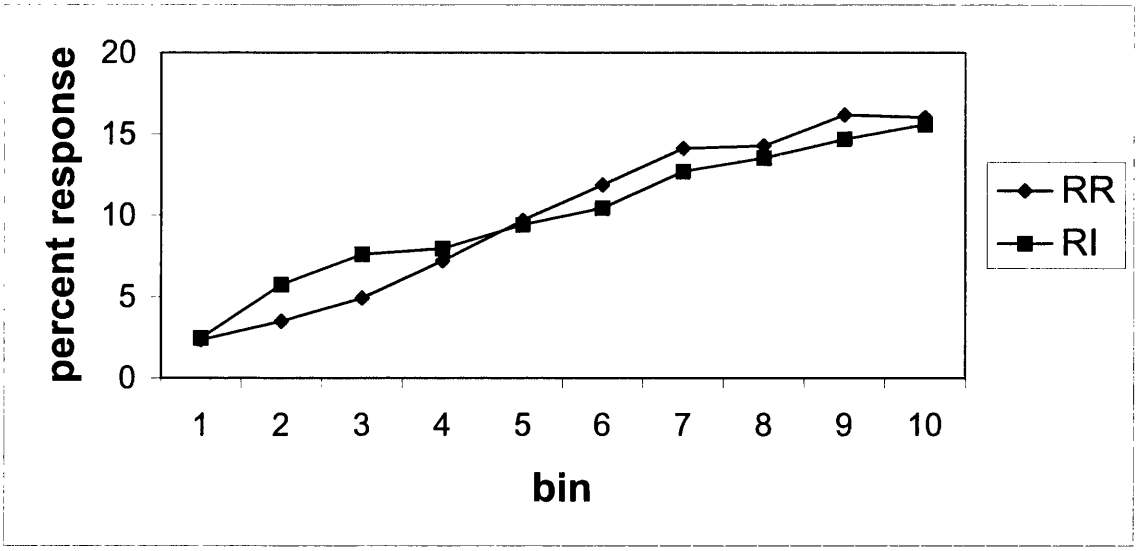

Figure 3.8 Block 3 (sessions 11-15) total responses over ten six-second bins for RR (history of random-ratio training) and RI (history of random-interval training)

Figure 3.8 shows percentage data from the third block of FI training sessions. Here, the noticeable spike in percentage at block 2 is notably absent from both components associated with the RI and RR pretraining, with the component associated with the previous RR schedule showing the beginning of a scalloping pattern in initial sessions. Although the progression is comparatively rougher for the RI set, a clear linear climb from low to high percentages of response can be seen as time progresses.

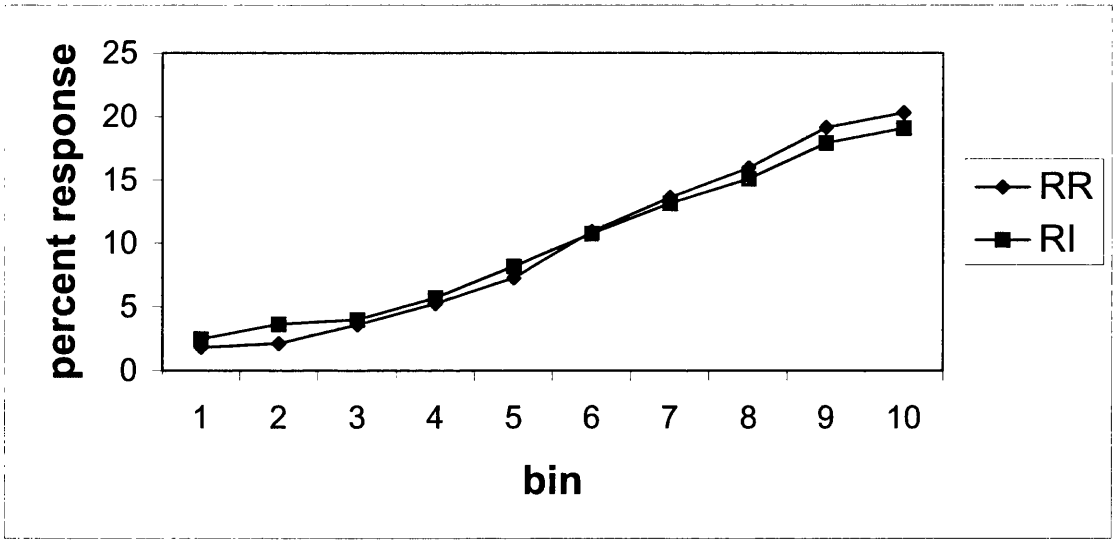

Figure 3.9 Block 4 (sessions 16-20) total responses over ten six-second bins for RR (history of random-ratio training) and RI (history of random-interval training)

Figure 3.9 shows the final block of five sessions for multiple FI, FI training in the components previously associated with the RR and RI pretraining. Unlike in previous blocks, differences between the components are virtually indistinguishable. As the percentage data is immune to rate of response, it better represents similarities between the groups at the conclusion of training, as well as marked dissimilarities in blocks 1 and 2.

A three-way repeated-measures ANOVA (schedule x block x bin) was carried out. The results showed a statistically significant main effect of bin ($F(9,54) = 23.81$, $p < .001$), a significant main effect of session ($F(3,18) = 8.62$, $p < .001$), and a statistically significant main effect of schedule ($F(1,6) = 47.24$, $p < .001$). Statistically significant interactions between bin and session ($F(27,162) = 52.76$, $p < .001$), bin and schedule ($F(9,54) = 4.32$, $p < .001$), and bin, session and

schedule ($F(27,162) = 7.34$, $p < .001$) were found. No significant interaction was noted between block and schedule for these data.

To further analyze these data, two-factor ANOVAs were carried out on the effect of schedule and bin within each block individually. For block one, there was a statistically significant main effect of bin ($F(9,54) = 56.46$, $p < .001$), and a statistically significant interaction between bin and schedule ($F(9,54) = 7.33$, $p < .001$). Block two showed a significant main effect of bin ($F(9,54) = 24.52$, $p < .001$), and a significant interaction between bin and schedule ($F(9,54) = 6.12$, $p < .001$), as well as a main effect of schedule ($F(1,6) = 10.84$, $p < .05$). The results from block three yielded statistically significant main effects of bin ($F(9,54) = 86.72$, $p < .001$), and schedule ($F(1,6) = 32.24$, $p < .001$). A main effect for the interaction between bin and schedule was also found for this block ($F(9,54) = 7.27$, $p < .001$). In the final block, statistically significant main effects were again reported for bin ($F(9,54) = 31.99$, $p < .001$), and schedule ($F(1,6) = 21.98$, $p < .01$), with a significant interaction between these variables ($F(9,54) = 6.85$, $p < .001$).

Finally, one-way ANOVAs with Bonferroni correction (amended rejection criteria set at $p < .005$) were carried out to evaluate the effect of schedule on percentage of total response occurring in each bin individually for each block. The results for block 1 showed significant effects at bin 1 ($F(1,12) = 14.36$, $p < .005$), bin 9 ($F(1,12) = 12.27$, $p < .005$), and bin 10 ($F(1,12) = 12.27$, $p < .005$). Block 2 showed significant effects of schedule only on bin 8 ($F(1,12) = 12.45$, $p < .005$), and 10 ($F(1,12) = 11.90$, $p < .005$). No significant differences between groups on any individual bin were reported for blocks 3 and 4.

Index of Curvature

Index of curvature (Fry, Kelleher & Cook, 1960) is used as per the previous chapter, and sets a value representative of response distribution throughout the interval. For this value, an even distribution occurs at 0, and a distribution condensed in the final bin occurs at .999. Higher values for the index of curvature indicate sharper scalloping and a higher concentration of responses in later bins. When this value is negative it is indicative of a decrease in rate of response over time; on a graph, this will appear as inverse scalloping.

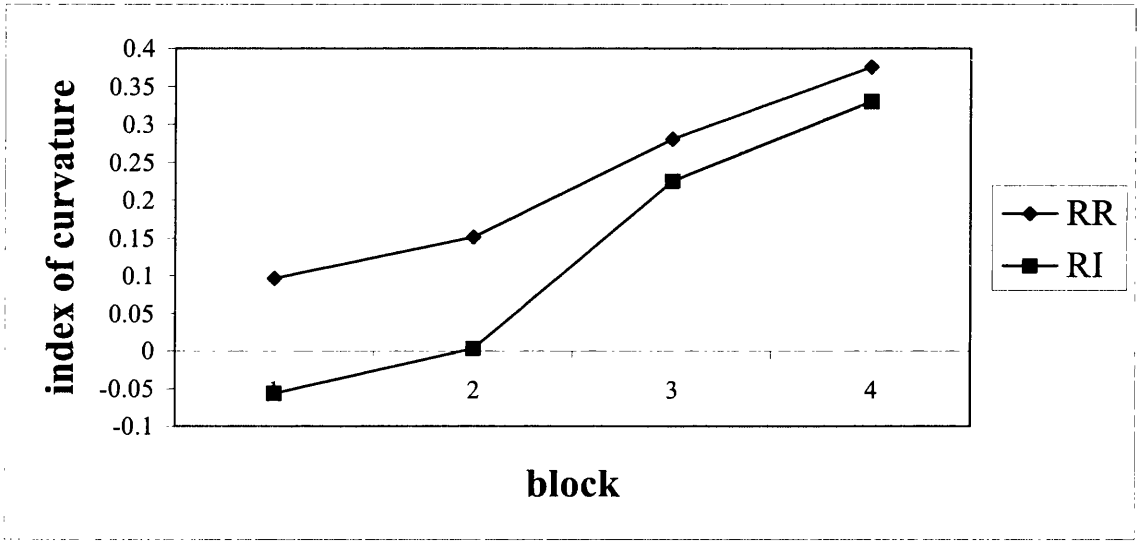

Figure 3.10 Index of curvature values for blocks 1-4 for RR (history of random-ratio training) and, RI (history of random-interval training)

An initial negative index of curvature is shown for the component associated with the previous RI training, with an initially slow increase in index of mean index of curvature values with each block of sessions. The component associated with the previous RR training shows no initial negative value for the

index of curvature, and has a more steady increase of index of curvature values over time.

A two-way, repeated-model ANOVA was conducted on the index of curvature data to evaluate the effects of block and schedule on index of curvature. This analysis revealed a statistically significant main effect of block ($F(3,18) = 114.79$, $p < .001$), and a significant main effect of schedule ($F(1,6) = 6.17$, $p < .05$). A significant interaction between schedule and block was also found ($F(3,18) = 6.77, p < .005$).

To further analyze these data, a series of one-way ANOVAs were carried out on the effect of schedule on index of curvature for each individual block. Bonferroni corrections for these data yielded rejection criteria of $p<.0125$. Results showed a significant effect of schedule on index of curvature only for block 2 ($F(1,12) = 16.56, p <.005$).

Quarter Life

As noted in the previous chapter, quarter life is a cumulative figure representing the amount of time passed in a session at which 25% of responses have been emitted. In a 100 second session, this value will be .25 (25%) if the rat has emitted a steady rate of response throughout the interval (25% or responses emitted at 25% of the interval). However, as the current sessions are set at 60 seconds, the value of the quarter life at which a steady response throughout the interval can be seen is .15 (or, one quarter of the time through the interval). When scalloping occurs, the value is expected to increase beyond this point with the intensity of the curvature (Cole, 2001; Baron & Leinenweber, 1995). Figures

lower than .15 indicate higher numbers of responses being made in the initial bins of the trial. Quarter life was calculated as per Chapter 2, and as such contains a small margin of error due to assumption of a linear relationship between the bins within which 25% of responses were emitted.

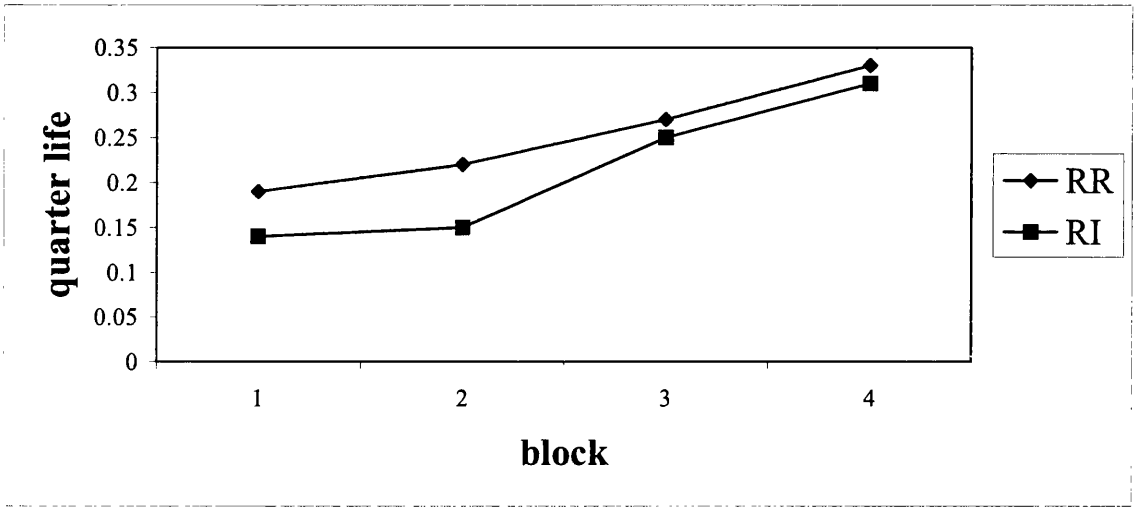

Figure 3.11 Quarter life values for blocks 1-4 for RR (history of random-ratio training) and, RI (history of random-interval training)

Figure 3.11 shows quarter lives (Hernstein & Morse, 1957) for each of four, five-session bins on RI performance. A lower quarter life value is seen for the component previously associated with the RI training initially, with little change the second block, and a much more drastic change to block three. In contrast, the component previously associated with the RR training increases on a nearly linear scale between each block. Both components associated with the RI and the RR previous training appear to perform similarly in the last two blocks for this value.

A two-factor, repeated-model ANOVA (schedule x block) revealed statistically significant main effects of block ($F(3,18) = 70.01$, $p < .001$), and schedule ($F(1,6) = 69.01$, $p < .001$), and an interaction between block and schedule ($F(3,18) = 3.34$, $p < .05$). As for Index of curvature analysis, one-way follow-up ANOVAs were then conducted for the effect of schedule on each block to evaluate where significant interactions might occur. Using the Bonferroni correction, rejection criteria set at $p < .0125$ for these analyses, the results showed a significant effect of schedule on quarter life for block 1 ($F(1,12) = 33.80$, $p < .001$), and for block 2 ($F(1,12) = 19.38$, $p < .001$). No significant effect of schedule on quarter life was found for blocks 3 or 4 ($ps > .0125$).

Discussion

As in the previous experiment (Chapter 2), these data support the hypothesis that prior exposure to a schedule of reinforcement can have an effect on responding observed during exposure to the next schedule which subjects experience. However, as with Chapter 2, this effect appears to be transient, and is dissipated by the conclusion of experimentation. This reflects previous findings that history training on an RR schedule shows some effect on subsequent FI performance (Cole, 2001; Freeman & Lattal, 1992; Okouchi, 2005), and contrasts the more lasting effects found by Wanchisen et al (1998) in animal subjects, and Wiener (1964) in humans. Although terminal baseline response rate and rate of reinforcement prior to the manipulation were not evaluated, as in chapter two they were comparable across groups, and do not seem to provide sufficient evidence for

causation of these difference. Follow-ups to this research could nonetheless focus on these data as a further source of evidence for history effects in these schedules.

The overall high rates of response found in previously ratio trained components, when compared to previous interval training (Ferster & Skinner, 1957), persisted even in FI training for this sample. However, differences in responding in bins across blocks showed the major differences existing primarily in the initial part of a reinforcement trial, with differences between responding constrained in the initial blocks of training as compared to later blocks. This reflects results found by Freeman and Lattal (1992), Cole (1991) and Baron and Leinenweber (1995), where a significant, but transient, effect of pretraining was shown to manifest in initial sessions of FI training. Unlike these studies, however, the present results show this effect in a within-subject, yoked sample, and as such will not manifest individual differences possible in between-subject models.

Although clearly present, the transience of the effect of historical schedule on performance can best be seen in the evaluation of percentage rather than response rate data. Here, by the conclusion of the experiment, percentage response across bins is virtually indistinguishable between the FI components previously associated with the RI and RR schedules. Review of graphical information for this data is particularly striking for block 2, where percentage of responses spikes significantly in the RI as compared to the RR group. This further demonstrates the differential response of RI pretraining on FI continuum in initial seconds of each session, with RI schedules showing much slower development of the scalloping response than RR schedules. The initially negative value of index of curvature for the previously RI-associated component indicates a convex shape

to the initial distribution, which then moves to a liner (as seen by a near zero index of curvature value) before aligning with previously RR-associated responses. That the latter component did not show this change, but instead progressed from low to high index of curvature values, indicates less disruption in the learning of a new, FI continuum for this group.

As another representation of the distribution of responses within blocks, quarter-life values show a similar pattern, with larger differences between the effects of the different histories occurring in blocks 1 and 2, after which RR and RI sets show nonsignificant differences. Again, the largest difference in value is seen for block 2, with the previously RI-associated schedule showing a significantly lower value than the previously RR-associated schedule. As with the index of curvature, however, the differences in performance become nonsignificant in blocks 3 and 4, and virtually identical by this time averaging at .31-.33 as would be typical of FI response training alone.

Overall, the data obtained from this study supports the hypothesis that RI pretraining will result in significantly inhibited ability to perform on a subsequent FI schedule, compared to RR pretraining. This reflects results found in previous studies, as well as in Chapter 2. The implications for these findings will be discussed in Chapter 5.

Chapter 4

Effects of Reinforcement History in Extinction

Behavioural research generally emphasizes the role of the current contingency on performance at the expense of historical contingencies. Originally posited by Ferster and Skinner (1957), this view assumes that the current contingencies will come to control performance without an effect of those variables related to historical contingencies. This view has been experimentally demonstrated a number of times in history effects research (e.g., Baron & Leinenweber, 1995; Freeman & Lattal, 1992). Such studies reveal that irrespective of historical training, given sufficient training on a new contingency, subjects will perform similarly to subjects with different reinforcement histories.

This view is supported also by the current research series; that is, Chapters 2 and 3 both demonstrated that, although present at initial phases of training, differences in performance based on historical paradigms became marginal after sufficient fixed-interval (FI) training had been administered.

Despite the lack of persistent differences due to prior training in current response rates, it is possible that latent effects of historical nonetheless persist as part of an organism's behavioural repertoire. Thus, although history effects can be transient in overt behaviour, they may have a larger influence at a future time. Such research demonstrating latent effect comes from a variety of sources, wherein a previously reinforced response (such as a lever press; see Doughty, Cirino, Mayfield, Da Silva, Okouchi, & Lattal, 1995) emerges into the current

behaviour of an organism despite the lack of presence of that response in current behaviour, or contingencies reinforcing that response.

When such latent effects reappear in an organism's behaviour, resurgence is said to occur. Epstein (1983) demonstrated the presence of resurgence in pigeons, showing a high incidence of historically trained behaviours (key pecking) in an extinction paradigm following reinforcement of non-key pecking behaviours. In a schedule-based, rather than behaviour-based, comparison, Pear (1985) observed behaviour patterns in pigeons trained first on VI 300-sec, and then on VI 15-sec schedules. In a following extinction condition, some pigeons emitted responses associated with the initial VI 300-sec schedule. This suggests a latent effect of the VI 300-sec schedule on responding that persisted despite not being observable during exposure to the VR 15-sec contingency. Resurgence has since been documented a number of times, using a variety of schedule- and behaviour-based measures in human (Mechner & Jones, 2001; Sajweh, Twatdosz, & Burke, 1972; Weiner, 1964, 1965, 1969; Wilson & Hayes, 1996), and in nonhuman populations (Cleland, Foster & Temple, 1999; Lieving & Lattal, 2003; Mowrer, 1940 Rawon, Leitenberg, Mulick, & Lefebvere, 1977; Sanders, 1937; Thomas & Sherman, 1986; Wanchisen, Tatham & Mooney, 1989).

Often termed 'extinction-induced resurgence' (Epstein, 1983), resurgence is most easily demonstrated in an extinction contingency involving both termination of the previously reinforced contingency and nondelivery of reinforcement (see Lerman & Iwata, 1996). In this context, an organism resorts to previous operative contingencies of behaviour when presented with an environment in which the current contingency has failed. The incidences of these

previously reinforced contingencies provides further evidence about the latency of history effects, as currently unobservable previous response sets arise in extinction paradigms (Leiving & Lattal, 2003; Mechner & Jones, 2001). As no behaviours are being reinforced during extinction, resurgence occurs only due to the existence of prior training, and not due to the present reinforcement of that response set.

During extinction, behaviour has also been shown to become increasingly variable. Schwartz (1982) demonstrated this in a college sample, wherein participants were asked to press two keys in any sequence to receive points. Although specific sequences were not required for reinforcement, most participants developed dominant sequences of response that were documented by a computer. In extinction training, the incidence of these dominant sequences decreased, and the incidence of novel sequences increased. Mechner and Jones (2001) also demonstrated a similar effect in a human population, using a pattern of lettered keys, and including starting and ending 'response-markers' to the response sequence. In this case, both the 'criterial' (taught, integral to the sequence), and 'noncriterial' responses, increased in incidence in extinction trials.

The current experiment proposes an examination of the impact of extinction phases on RI and RR pretrained rats, following an interposed FI contingency. These histories have been shown to produce differential rates of response prior to FI training (Ferster & Skinner, 1957). After subsequent, prolonged FI training, rates of response on FI schedules, despite the differences engendered prior to FI exposure by the previous RI or RR training, are roughly equal (see Chapter 3). It is hypothesized that RI and RR training histories will show a latent effect on performance during extinction; that is, while not

observable during the extended FI training, differences in response rates will reappear during exposure to an extinction contingency. This should take the form of a heightened rate of response in subjects with conditioning histories associated with a high rate of response (RR), as compared to those subjects with conditioning histories associated with a lower rate of response (RI).

Method

Subjects

Sixteen, male Lister hooded rats (seven of which were used in Chapter 3), served in this study. The animals were all between three and four months of age, and experimentally naïve at the onset of the experiment. Subjects were initially weighed and maintained at 85% of their free-feeding weight for the duration of the procedure. Group housing of three to four animals was maintained, and all animals had free access to water in the home cage.

Apparatus

As in previous studies, sessions were conducted in a closed laboratory with a maintained environment. Four, standard 23.5 x 23.5 x 23.5 cm operant conditioning chambers were used, identical to those used in Chapters 2 and 3. Each chamber contained two, retractable levers, with a light located above each lever, and a recessed food hopper located equidistant to each lever. Reinforcement consisted of 45-mg standard Noyes food pellets, and was delivered to the food hopper as indicated. The operant chambers were located in larger, light-blocking,

sound absorbing wooden boxes with outside noise blocked by a ventilator fan for each box.

Procedure

As described in Chapter 3, subjects were given magazine training on two, twenty-minute, random-time 60-second sessions, then were taught to press a lever for food reinforcement on two, twenty-minute continuous-reinforcement (CRF) schedules. During the first session the left lever was extended into the chamber with the right retracted, and during the second session the right lever was inserted into the chamber with the left retracted. This was done to ensure that all subjects were equally trained to press each lever independently. Each of these sessions was twenty minutes in duration.

Rats were then exposed to a multiple CRF, CRF schedule for two, thirty-minute sessions. Within this contingency, the light above each lever was lit alternately for five minutes cueing the associated lever as 'active'. When the light above a particular lever was lit, only responses made on that lever (and not the other lever) were reinforced. After each five-minute component on a lever, an inter-component interval (ICI) of thirty seconds was presented, during which no lights were lit. After this ICI, the light above the opposite lever would be lit, indicating the lever which was previously inactive was then active. This procedure was repeated six times over a session, with three, five-minute exposures presented on each lever in alternating order.

Following this training, the rats were divided into two groups, with eight rats exposed to a multiple random-ratio (RR), random-interval (RI) schedule. Of

this set of eight, four of the rats were given RR training on the right lever and RI on the left, and four of the rats were given RR training on the left lever and RI on the right. The components of the RR, RI schedule were then presented in alternation, with the mean inter-reinforcement interval (IRI) on the RR schedule during one component serving as the mean IRI for the RI schedule in the following component. The RR criterion value was increased over the course of training as follows: Sessions 3-4, RR-5; Sessions 5-6, RR-10; Sessions 7-8, RR-15; Sessions 9-10, RR-20; Sessions 11-12, RR-25; Sessions 13-40, RR-30. Sessions consisted of six, five-minute exposures to the RR schedule, and six, five-minute exposures to the RI schedule. Rats not in this group received no training during this time. These rats (plus one rat receiving the multiple RR, RI schedule) were run following the initial seven rats described in Chapter 3 in a second replication of the study However, as all variables except the time were identical between the replications, all rats are analysed together in this Chapter.

All rats were then exposed to a multiple FI 60-seconds, FI 60-seconds schedule. Sessions were conducted as described above, with six, five-minute exposures to each lever, signalled by the illumination of the light associated with the active lever. Again, exposures were separated by a thirty-second ICI, and components were presented in alteration. This training continued for 36 sessions. This training took place as part of the experimental paradigm presented in Chapter 3. However, training on the final multiple FI 60-sec, FI 60-sec schedule for the seven rats described in Chapter 3, continued after that data reported in Chapter 3, to ensure performance was identical across the two components of the multiple schedule prior to the extinction phase.

After completion of the phase described above, the subjects were each given two, twenty-minute exposures to a multiple extinction, extinction schedule. During this time, sessions proceeded as above, but with two, five-minute exposures for each lever, during which a light associated with a lever would be lit. Although responses to the active lever were recorded, no reinforcement was given for the duration of these sessions and no contingencies were presented for either lever. The order in which extinction was presented was counterbalanced across groups to ensure that the lever associated with either RR or RI schedules was only presented first for half of the subjects.

Results

As this manipulation followed up that described and analysed in Chapter 3, the primary focus of the current study lies not in the transient history effects seen in the transfer of RI and RR to FI responding, but rather to the possible appearance of different response patterns in the extinction condition. As such, the results are mainly discussed with regard to differences in responding prior to and within this extinction condition.

Figure 4.1 shows mean response rates emitted by both groups (those given prior multiple RR, RI schedule training, and those not given such training) on each component of the schedules, both during pretraining, and during the FI contingencies. Data from the initial training phases (multiple RR, RI schedule) shows initially similar rates of response in both components, with the RR schedule resulting in steadily climbing rates of response over time. In contrast, the RI schedule shows a much slower increase in rate of response, with final rates

appearing quite low in comparison with RR response rates. A paired-sample t-test was conducted to compare rate of response at the conclusion of training. This analysis showed a significant difference between RR and RI response rates ($t(15) = 6.52, p < .05$).

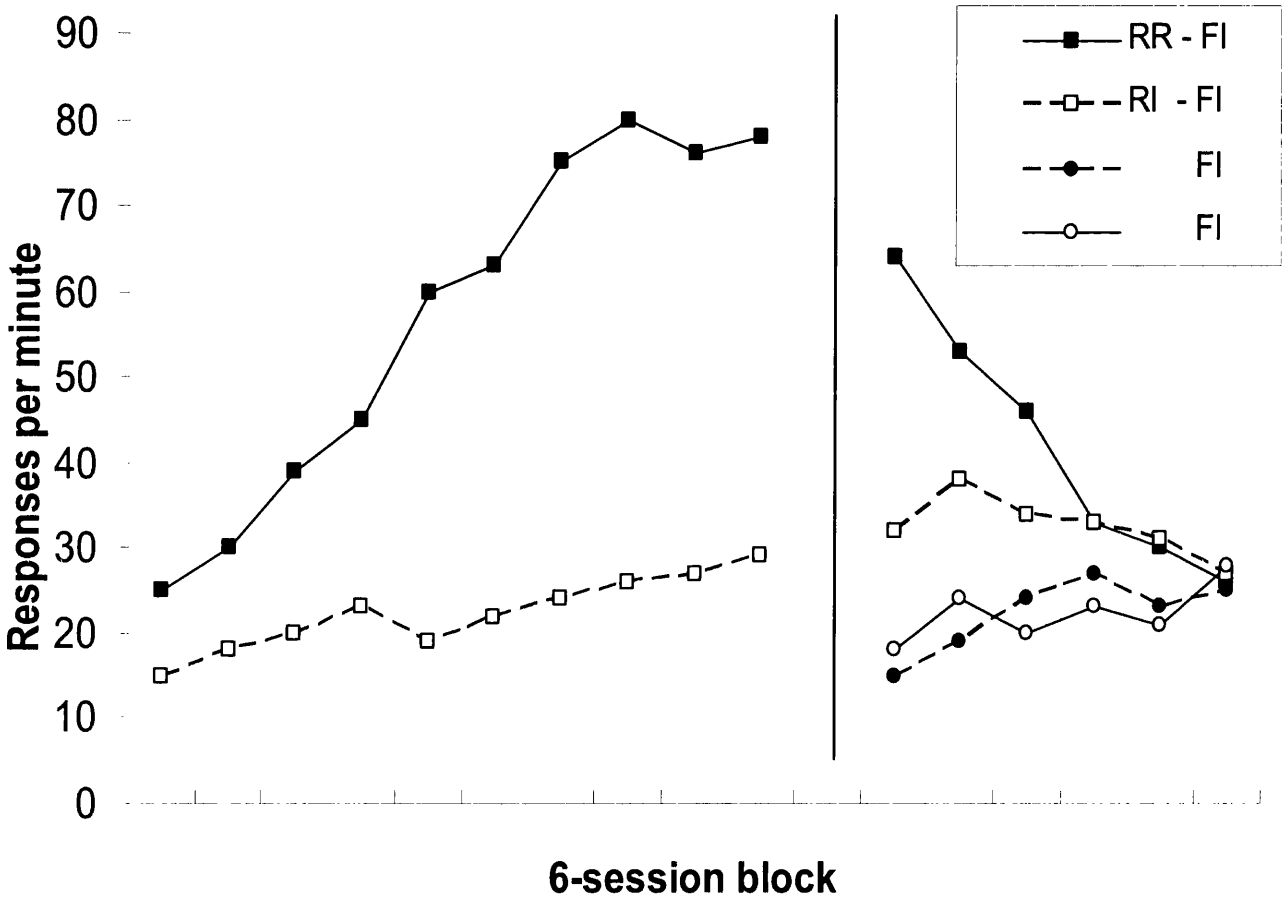

Figure 4.1. Mean response rate in RI (history of random-interval training) and RR (history of random-ratio training) on pretraining and RI, RR and FI (exposure only to fixed-interval training) on an FI schedule

During the multiple FI, FI schedule training, rates of response emitted in the group previously given the multiple RR, RI schedule appear identical to the multiple FI, FI only group by the termination of this training phase (Figure 4.1). Rates on the FI component previously associated with the RR component appear higher than the FI component rates previously associated with the RI component, until approximately 15 sessions of training have passed (3, six-session blocks). In contrast, rates on the FI component previously associated with the RI component appear relatively constant with the previous rate. Though initially low, rates in the FI, FI only group converged with those of the RR, RI group by termination of FI training, with nearly indistinguishable response rates across schedules at this time.

A two-factor analysis of variance (ANOVA) was carried out on the final block of training, with group as a between-subject factor, and component of training as a within-subject factor, for the last block of training. However, no significant main effects or interactions were reported ($F < 1$ for all comparisons).

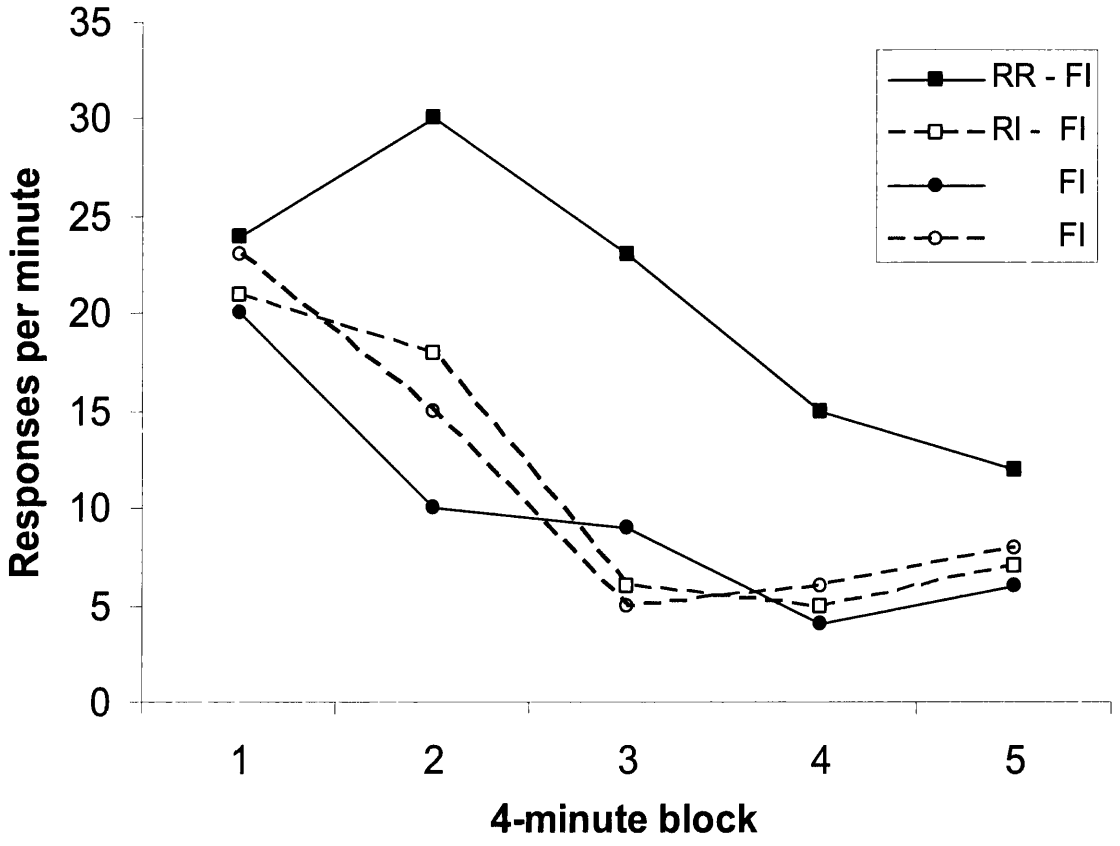

Figure 4.2 mean rate of response over two extinction sessions for RI (history of random-interval training), RR (history of random-ratio training) and FI (exposure only to FI contingencies)

As behaviour was similar across extinction sessions these data were collapsed to include all extinction sessions. Figure 4.2 shows group mean rates of response over the extinction sessions (represented as successive four minute periods of extinction). In the FI, FI only group, rates of response can be seen to decline over the course of extinction, eventually reaching roughly equivalent rates of response in each component by termination of the extinction phase. In contrast, although response rates also eventually declined, the RR, RI group showed different patterns of decline across the four-minute blocks in each component.

Similar to the pattern of responding in the FI, FI only group, responding in the component previously associated with the RI schedule showed an initial slow, then sharper decline, and increasing very slightly over the last few blocks. However, responding in the component previously associated with the RR schedule shows an initial sharp increase in response rate, before showing a declining pattern.

A three-factor ANOVA (group x component x block) was conducted on these data, revealing statistically significant main effects of group ($F(1,14) = 61.01, p < .05$), component ($F(1,14) = 26.32, p < .05$), and block ($F(4,56) = 55.89, p < .05$). The interaction effects between group and component ($F(4,56) = 5.57, p < .05$), group and block ($F(4,56) = 5.49, p < .05$), and component and block ($F(4,56) = 5.57, p < .05$) were also statistically significant. These interactions were followed up using two-factor ANOVAs, as described in Chapters 2 and 3, with a component by block analysis conducted for each group. These analyses showed a significant main effect of block ($F(4,28) = 40.76, p < .05$), but not for component, nor interaction ($ps > 0.1$), in the FI, FI only group. The ANOVA results for the RR, RI group showed a significant main effect of block ($F(4,28) = 25.19, p < .05$), a significant main effect of component ($F(1,7) = 43.31, p < .05$), and a significant interaction between block and component ($F(4,28) = 3.50, p < .05$). The interaction was further analyzed by a series of paired t-tests conducted between the RR and RI schedules on each block (using a Bonferroni correction, new rejection criterion is $p < .01$). These analyses revealed a statistically significant difference between the RR and RI associated components on blocks 2, 3, and 4 (smallest $t(7) = 2.97, p < .01$).

Discussion

The present results showed that in the initial stage of training there were high rates of response in the RR component compared to the RI component. Although baseline data was not presented, as in other chapters these data were considered similar across groups prior to manipulations. This effect reflects previous studies on response rate in an animal sample (Skinner, 1938), and replicates previous within-subject demonstrations of comparisons between ratio and interval performance (Peele, Casey & Silberberg, 1984; Reed, Hildebrandt, DeJohgh & Soh, 2003). This effect is further replicated, even in conditions where reinforcement rates are matched (e.g., Cole, 1994), and demonstrates the presence of significantly different rates of response in RR and RI contingencies prior to FI training. The development of differing rates of response in RR and RI training served as the background for testing the resurgence of these response patterns in the extinction condition. As the rates of response showed a significant difference by the end of training on RR, RI contingencies, this difference was successfully established in RR, RI rats and could then be tested later in the experiment.

The data obtained from the second phase of the experiment (multiple FI, FI) were discussed in detail in Chapter 3. Hence, these data will not be discussed here, except to note that by the end of this phase, response rates were identical in the components of the multiple FI, FI schedule for rats previously exposed to multiple RR, RI schedule, and also to the rates emitted by rats exposed to no previous contingencies. Thus, any differences in the rate of response during extinction must reflect difference in the previous history training of the rats.

The results obtained in the extinction phase support the initial hypothesis that different histories (RR versus RI) result in significantly different responding in an extinction contingency. The RR schedule pretraining seemed to show a different pattern to both the RI schedule, and no training, during extinction. The RR pretraining lead to an 'extinction burst' occurring early in the test phase. Previous research indicates that responding during extinction can often be characterized by this phenomenon (Kazdin, 1994; Martin & Pear, 1992). As responses were only recorded for the active lever and included only one response measurement (depression of the lever), variability of response was not evaluated for this study, although previous studies would indicate that variability would also be increased (Antonitis, 1951; Mechner & Jones, 2001; Schwartz, 1982).

Rats with previous multiple RR, RI training showed significantly different patterns of response across the components in the extinction condition, with RR training demonstrating initially higher rates than the other conditions, and RI and no history training showing the decline in response rate that is often described as characteristic of the extinction paradigm (see Lerman & Iwata, 1996). This indicates that the behavioural history can have a latent effect on performance that although not discernable in currently reinforced paradigms, is revealed upon transfer to an extinction contingency.

Thus the current results show that responding in components previously associated with a high rate of response increased relative to responding associated with a low rate of response. This demonstrates evidence of resurgence of previous responding rates relative to schedule patterns. Of further interest could be the relation between previous training and subsequent responding in extinction; that

is, whether training on a contingency encouraging low rates of response would also lead to less overall responding in an extinction paradigm. This would be particularly interesting given that one would expect more training to result in better resistance to extinction (Mikulka & Klein, 1980).

This resurgence, or reversion to previously reinforced behaviour, demonstrates the duration of history effects may not be as transient as previously argued (Cole, 2001; Freeman & Lattal, 1992), but may lie latent in the behavioural repertoire of the organism. It suggests also that the effect of previous training on subsequent behaviour may be subject to a number of variables such as the nature of the current contingency.

Chapter 5

Discussion of Results: History Effects in Context

The current thesis proposed a two-experiment sequence for demonstrating scheduled history effects in a nonhuman sample, followed by an examination of these same history effects in an extinction paradigm. Given previous demonstrations of history effects on fixed-interval (FI) contingencies (Baron & Leinenweber, 1995; Cole, 2001; Francois & Metzger, 1993; Freeman & Lattal, 1992; Lopez & Menez, 2005; Wanchisen, Tatham & Mooney, 1989; Weiner, 1964, 1969, 1970), it was expected that ratio histories would show some effect on subsequent performance in, at least, initial FI response patterns. The current results were examined with particular attention to the data presented by Wanchisen et al. (1989), where variable-ratio (VR) pretrained rats showed little evidence of developing traditional FI patterns of response even after extensive exposure to an FI continuum. Although striking, these results had not been replicated in a nonhuman sample.

Although history effects — and particularly those of past ratio training (e.g., Baron & Leinenweber, 1995; Cole, 2001; Freeman & Lattal, 1992; Lopez & Menez, 2005) — have previously been demonstrated in FI performance, the possibility of a latent history effect in these samples had not been fully addressed. However, previously learned behaviours have been shown to show a resurgence effect in extinction contingencies (Mechner & Jones, 2001), suggesting that history effects may have a latent presence in an organism's behavioural repertoire, even if their presence is not observable in a given environment. Following from

this, it was expected that despite emitting highly similar responses in an FI continuum, rats with different reinforcement histories would emit responses reflecting those histories when exposed to an extinction paradigm.

The present experiments show an effect of behavioural history and response rate in historical paradigms in both between- and within-subject designs. However, there is also support for the emphasis on current contingencies over previous ones given sufficient training. In both Chapters 2 and 3, by the termination of training, performance was virtually indistinguishable irrespective of historical training. Despite this, some latent history effects could be seen in differential response to extinction for RR and RI histories (Chapter 4).

Though this presents evidence of a transient history effect in the learning process, the specific nature of that effect, and its various manifestations, could be further examined. Previously reinforced responses have been shown to arise despite a lack of reinforcement in current contingencies in both resurgence (Mechner, Hyten, Field & Madden, 1997), and reinstatement (Doughty, Reed & Lattal, 2005), studies. Further, this phenomena has demonstrated as both lasting (Wanchisen, Tatham & Mooney, 1989), and transient (Freeman & Lattal, 1992) effects, although it appears that sufficient exposure to a new contingency will eventually suppress these behaviours (Baron & Leinenweber, 1995; Cole, 2001; Freeman & Lattal, 1992; Okouchi, 2005). Specific to FI performance following VR or FR pre-training, significant history effects appear not to linger beyond 20-30 trials exposure to an FI contingency (Baron & Leinenweber, 1995; Cole, 2001; Freeman & Lattal, 1992).

5.1 The Effects of RR Pretraining on Subsequent FI Performance

The present results showed that there were transient effects of prior training on ratio schedules on subsequent FI performance. These transient effects were similar to those noted by Freeman and Lattal (1992). Comparable results were also reported by Cole (2001), where mid-way through FI training, rats with a ratio history showed longer post-reinforcement pauses, and higher rates of response, than did differential-reinforcement-of-low-rates (DRL) trained rats. As in the current Chapters 2 and 3, however, Cole (2001) reported nearly identical scalloping in all groups by the conclusion of the experiment.

Significant effects of ratio training on FI performance was reported by LeFrancois and Metzer (1993) and Lopez and Menez (2005), both of whom report initially high rates of response for historical ratio groups. These results are in the same direction as those reported by Wanchisen et al (1989), but failed to replicate the duration of observable effects reported in this latter study. Although it was certainly clear that these effects were not long lasting, there was no suggestion that they could not be found as in the data reported by Baron and Leinenweber (1995).

However, the current results did not support the view developed by Wanchisen et al. (1989) that human FI performance is characteristically different from that noted in nonhumans primarily due to prior exposure to ratio schedules. Two lines of evidence suggest this is not a sufficient explanation of the findings. First, the effects noted in the present study were relatively transient, and those reported in humans (Bentall et al., 1985; Wiener, 1964; 1969; 1970a) are long lasting. Secondly, it is clear that it is not just exposure to ratio schedules which produces differences in the pattern of responding on subsequent exposure to FI

schedules. In fact, prior exposure to RI schedules also produces a delay in developing a scalloped pattern of responding. This delay is even more pronounced than the retardation found after exposure to ratio schedules, suggested by Wanchisen et al. (1989). Whatever the explanation of human performance, it seems clear that exposure to ratio schedules prior to exposure to FI schedules in the experimental context is not a strong candidate explanation (this is discussed in more detail below).

5.2 The Effects of RI Pretraining on Subsequent FI Performance

Results showing that RI schedules can have an impact on subsequent FI performance have not been thoroughly documented in previous research. This is surprising given the strength of the effect found in the current studies (in many cases, the impact of previous RI training was stronger than that for RR pretraining; see Chapters 2 and 3). Of particular importance are the results showing a significant difference for pretraining in overall rates of response in subsequent FI training, although this effect does diminish as exposure to FI conditions continues. This effect is not wholly unexpected, as it corroborates some results reported by Freeman and Lattal (1992), and to a lesser degree those reported by Wanchisen et al. (1989). However, these results concerning the impact of RI pretraining are also opposed to those reported by Baron and Leinenweber (1995), where very few history effects were found.

Most importantly, the current data suggests that prior exposure to RR conditions does not have as large an inhibitory effect on the development of FI performance, as prior exposure to RI conditions. The consistent finding of a main

effect of exposure to a RI schedule, shows RI history hindering the development of the post-reinforcement pause typically seen in response under FI conditions. This effect is relatively novel, and will obviously require further experimental investigation to isolate the mechanisms involved.

The finding that interval schedules produce stronger retardation of the development of FI responding than ratio schedules could be due to a number of reasons. Although the current data do not allow unambiguous determination of the source of this effect, a few possible causes of this effect are worth brief mention. One possibility could obviously be different rates of reinforcement between the two schedules. However, the effect of differential rates of reinforcement between RI and RR training was compensated for using the yoking procedure in both demonstrations (Chapter 2 and Chapter 3). This yoking procedure, thus, rules out this as a possible explanation of the current results.

However, it seems clear that differences in response rate between the RR and RI schedules, and differences in the nature of the schedule control produced by the two history schedules, could both have significant effects on development of FI performance. With respect to differences in response rate, there is a suggestion in some studies that resurgence is, to some extent, dependent on response rate (e.g., Doughty et al., 2004). In these studies, higher rates tend to lead to greater resurgence of responding. It is unclear, however, how this would explain the specific patterning effects of prior exposure to RR and RI schedules on subsequent FI performance; further work is obviously required in this area.

One possible factor explaining differences between RR and RI schedules is the differing kinds of control exerted over behaviour by the schedules. An effect

noted in the difference in rates of response immediately following reinforcement. On schedules, such as RR schedules, rates are slightly lower following reinforcement than are observed on RI schedules. This is an effect that has been experimentally demonstrated (Leslie, 1981; Zeiler, 1977). This may be due to the fact that the first response after reinforcement has a good possibility of being reinforced on an RI schedule, but is less likely to be reinforced on RR schedule. In RI schedules, the delivery of reinforcement does not necessarily signal the absence of subsequent reinforcement for a given period of time as in a ratio schedule. This is because in ratio schedules, a finite amount of time must elapse for the organism to emit the required number of responses to elicit the next reinforcement.

Following this observation, receiving reinforcement could come to act as an inhibitory cue (indicating to the animal that reinforcement is unlikely on future responses, thus, inhibiting those responses from being emitted) on the RR schedule, but not the RI contingency. Inhibition of post-reinforcement responding, in this case, reflects the inhibitory properties of reinforcement found in FI schedules (Dews, 1970; Gallistel & Gibbon, in press). Transfer from schedules with some inhibitory control of reinforcement (as depicted in FI schedules; Dews, 1970; Gallistel & Gibbons, in press) to schedules with similar characteristics may facilitate emission of response patterns common to both schedules. That is, this greater similarity between the RR and FI schedules, relative to the RI and FI schedules, may facilitate transfer to normal FI responding.

That ratio schedules may demonstrate some inhibitory control and, thus, transfer performance more easily to similarly controlled schedules (e.g., FI

schedules), drives a potential line of research investigating this point. Comparisons between different ratio schedules with varying degrees of inhibitory control (e.g., FR, VR, and RR), but equal rates reinforcement, would reveal more about the relation of inhibition to schedule transfer. Similarly, comparisons between schedules high and low in inhibitory control, but equivalent in response rate, would better demonstrate the effect of inhibition independent of differences in rate of response (as seen in RI and RR groups).

These current data, and the above explanation, may also go some way to resolving the apparent pattern of discrepant results seen in the literature, and suggests a straightforward explanation of the history effects seen when transferring onto FI schedules. When transferring to schedules that contain a characteristic postreinforcement pause, schedules that already demonstrate inhibitory control, whether strong or weak (such as RR), are able to transfer more readily that those without such inhibitory control. Although this suggestion fails to address differences between human and nonhuman performance on schedules with a postreinforcement pause, it does prompt future research better delineating the transfer of inhibitory control between schedules.

It is clear that the present data from Chapters 2 and 3, and the above explanation, are consistent with previous studies of history effects. Cole (2001) noted better transfer to FI responding patterns when DRL (a schedule high in inhibitory control) and fixed ratio (FR; a schedule low in inhibitory control) contingencies were used. Although not as high in inhibitory control as DRL schedules, FR schedules seem to transfer more fluidly than do VR schedules (see Baron & Leinenweber, 1995; Freeman & Lattal, 1992). Wanchisen et al. (1989)

also reported stronger history effects when transferring from a DRL (high inhibitory control) schedule to an FR (weaker inhibitory control) in the development of postreinforcement pausing. This effect was, however, not reported when transferring from FR to DRL schedules. A clear delineation of the incidence of postreinforcement pauses across schedules would be useful in this research, particularly as compared to theorized levels of inhibitory control. The presence of differences in the effects of exposure to ratio and interval schedules prior to explore to FI schedule also suggests that inhibitory control may have some interaction with these effects.

5.3 Differences in Animal and Human Models

One reason why the study of history effects on current FI schedules is so prominent in this field may reflect the putative explanation it offers of the differences between human and nonhuman FI schedule performance. On FI schedules, human subjects rarely show the scalloping characteristic of nonhuman samples, instead humans emit a more consistent rate of response across the interval (Weiner, 1969, 1970). This effect has been shown by others, and has been linked to the development of language in humans (Lowe, Beasty & Bentall, 1983). Moreover, this effect is of critical contemporary relevance to behaviour analysis. The importance of species differences, especially nonhuman to human, reflects a challenge to the assumption that behaviour is continuous across species, and that information garnered from human and nonhuman response can be directly applied to either species (Hayes & Hayes, 1992).

Interestingly, differences in human and animal behaviour in the FI continuum have also been noted in terms of humans 'counting out' the interval despite not having been told to do so (Barnes, 1989), behaviour that further supports some relation to verbal abilities. Barnes and Keenan (1989) initially attempted to further document human FI performance using visually distinct stimuli (computers located in different rooms), finding some evidence that access to a neutral location – in this case, a 'relaxation room' where no contingencies were present—resulted in more characteristic pause-respond patterns. In a follow-up, the same authors later also noted scalloping patterns in human response on FI 60, 300, and 600 schedules in the absence of overt verbal regulation (Barnes & Keenan, 1993), although the presence of these patterns appeared to be contingent on the presence or absence of other, distracting stimuli (e.g., television or reading material). In contrast to much past research, these results suggest that further examination of differences between species may best be addressed through the manipulation of human behaviour to approximate that of non-humans.

As an alternative to the language hypothesis (Lowe, Beasty & Bentall, 1983), Wanchisen et al. (1998) suggested that differences between animal and human performance on FI schedules are primarily moderated by an uncontrolled and non-specific exposure of humans to ratio schedules in everyday life. If this explanation were the case, the similar disrupted FI performance should be seen in any species with a history of ratio training. Although Wanchisen et al. (1998) were successful in demonstrating disruption of normal FI performance in animal subjects following VR training, with response patterns never reflecting those

characteristic of animal subjects, responses never developed into patterns similar to those exhibited by humans.

The results from the present Chapter 2 (between-subject), and Chapter 3 (within-subject), suggest that a strict RR (or even RI) history prior to exposure to the FI schedule is insufficient to produce human-like responding in rats on FI schedules. In the present studies, all rats eventually showed characteristic scalloping patterns when exposed to FI schedules, as evidenced by higher indices of curvature for all groups by the conclusion of the study, irrespective of their history training.

Despite this lack of evidence, some questions remain as to the effect of both training duration and complexity of previous reinforcement histories. As the exact reinforcement schedules to which humans are exposed in everyday life are unknown, these conditions may prove nearly impossible to replicate in nonhuman samples. In the current studies, the RR and RI histories were of limited duration, and tightly controlled in that only one type of schedule value was experienced for each animal. It can be argued that this fails to accurately reflect the human experience, in which reinforcement for a wide variety of behaviours occurs on an even wider variety of schedules, most of which will be RR, but some of which could occur along other undefined continua. There is evidence that multiple exemplar training is critical in generating novel and derived patterns of responses not present after single exposures to particular contingencies. Mechner and Jones (2001) showed an increase in novel key sequences in extinction phases, as well as significant history effects for previously taught sequences, after lengthy training. Owen (2002) argues that the idea of multiple exemplars is particularly important

in the development of language, where a large community provides an individual with multiple exemplars of proper verbal behaviour, which are then reinforced differentially across various contexts. Even given multiple exemplars, it should be noted that this history training does not generalise across subjects to produce similar effects in the human sample. Although prior VR training does seems to result in similar response rates in most humans on subsequent exposure to FI schedules, a subset of the population will respond at low constant rates as opposed to high constant rates (Weiner, 1969; 1970).

Due to difficulties in accurately recording pretraining experience in human samples, true experimental demonstration of a human history in a rat sample may be impossible to achieve. Were such a history applied to animal populations, however, it is possible that results similar to those found by Wanchisen et al. (1998), and Weiner (1964; 1969), might be produced, with durable interference in scalloped responding.

The demonstration of, at least, transitory effects in several experiments does suggest some impact of history on current contingencies (Freeman & Lattal, 1992; Okouchi, 2005). The interaction of more complicated histories on subsequent performance may thus be considered a significant area for future research, possibly leading to better ties between human and animal FI performance.

Irrespective of the above provisos regarding the possibility of comparing human FI performance to that of nonhumans after training on ratio schedules, the present study (and those reported in previous work) suggests this model is not likely to explain the full difference between the species. There are of course many

differences between the experimental procedures for rats and humans, but the language hypothesis — that human and nonhuman behaviour is fundamentally different due to the presence of language in the former (Barnes, 1989; Lowe, 1979) — remains viable in the face of these results.

Demonstrations of the effect of language on human behaviour have showed striking results in support of the language hypothesis, and particularly as relates to verbal instructions conveyed from the researcher to participants. Weiner (1970b) compared extinction responding in groups that had either been told nothing, or had been verbally informed that they could earn up to 700 or 999 pennies during the experiment. Responding in extinction was highest for groups given no instructions, and lowest for groups told they could only earn 700 pennies. As all groups were no longer reinforced after earning 700 pennies, differential rates of response could be attributed to the effect of verbal information prior to the study. If, as the language hypothesis suggests, differences such as those reported in Weiner (1970b) are universal in human experience, then this could be the source of the variation between human and nonhuman responding (Barnes, 1989).

5.4 Extinction and Resurgence of Previously Reinforced Behaviours

The study presented in the current Chapter 4 supplies some evidence of a latent effect of historical training paradigms on performance that reappears during exposure to an extinction contingency. The present results show this effect manifested by the presence of high rates of response in subjects historically trained to emit high rates. This effect was seen despite there being no evidence of the effect of the previous high rate training in the performance of the subjects

immediately prior to extinction. This reversion to previously schedule-controlled behaviour is known as resurgence, and has been previously demonstrated in a number of populations (see Epstein, 1983; Lieving & Lattal, 2003; Mechner & Jones, 2001; Rawon, Leitenberg, Mulick, & Lefebvere, 1977; Thomas & Sherman, 1986).

Cleland, Foster and Temple (1999) argue that resurgence in an extinction condition is mediated by the effect of repeated extinction conditions in a within-subjects design. Using hens as subjects, the experimenters designed a series of studies meant to isolate the variables mediating the incidence of resurgence in extinction. Subjects were first trained on behaviour one, then given a period of extinction. Following this, behaviour two was trained, and subjects were given seven sessions of extinction. The entire sequence (behaviours one and two plus extinction) was repeated a total of six times, with resurgence of behaviour one, during extinction phases of behaviour two, reported as highly variable and increasing over the six repetitions of the training sequence. As such, the authors concluded that the effect of repeated extinction conditions has a moderating role on the incidence of resurgence. In follow-up phases, the authors also present evidence that resurgence of behaviour one is of higher incidence when no extinction phase occurs after the training of behaviour one, and that this resurgence is more marked in the first session of extinction of behaviour two.

As the current study (reported in Chapter 4) did not include an extinction phase for the first behaviour (or RR/RI reinforcement contingency), it is possible that results suggest the incidence of resurgence in the extinction of the FI response is moderated by the prevention of extinction of behaviour one by the training of

behaviour two. The inclusion of an extinction phase in the current research may have affected the interference in FI response demonstrated in Chapters 2 and 3, and were thus inapplicable to the current research. However, to better document the resurgence effect in extinction, future research could compare both subsequent FI training and resurgence in extinction for two groups of rats: one group receiving extinction of initial RI or RR training, and one group receiving a non-extinction control. Comparisons between the groups could better demonstrate the incidence of extinction-induced resurgence, and would provide more detailed information about the effect of historical paradigms in the learning of new contingencies.

Investigations into the differences in extinction behaviour could focus on history effects, and particularly on the higher rates of response seen in previous ratio training during extinction. This effect was present despite control of reinforcement rate through the yoking procedure, and provides particularly strong evidence that during extinction, rats exhibit behaviours consistent with historically reinforced contingencies. Of special interest may be the effect of low-rate histories on later extinction performance, where lower rates of response could be used to predict similarly low rates of response in extinction. Rudimentary effects of this nature can be seen in chapter 4 (see Figure 4.2), where FI trained rats showed much lower rates of response that did RI and RR rats during extinction; similarly, RI rats showed lower rates of response than did RR rats.

As FI schedules traditionally demonstrate lower rates of response than either RR or RI conditions (Skinner, 1953; Tarpy, 1983), it is possible that this effect may be sustained historically during extinction, despite a predicted

resistance to extinction for this group. Of interest may be the effect of high and low FI schedules in extinction. Shull, Gaynor and Grimes (2002) demonstrated that resistance to extinction was higher for FI 60-sec as compared to FI 240-sec conditions, a relationship that could also be addressed in ratio conditions. However, current results demonstrate that a differential response to extinction is maintained even when conditions have identical rates of reinforcement. Replication of this result would also be of interest, as it conflicts with current theories that model extinction response as a function of response rate (Nevin, McLean & Grace, 2001).

Further, future results could compare both extinction rates across groups as well as response rates as a proportion of baseline behaviour. Although the current sequence of studies did not provide results in comparison to baseline, it's possible that behaviour can be further manipulated relative to baseline rates of response as well as baseline rates of reinforcement in both extinction and differential schedule paradigms. These data reflect those of Nevin (2003; e& Grace, Holland, & McLean, 2001), and could be particularly revealing in studies using schedules resulting in extremely low rates of response (such as DRL), and may be an area for future research into the specific nature of such history effects.

Although Chapter 4 demonstrates that historical schedules can have an effect on extinction performance, the exact nature of this performance is not well delineated. One reason for this is because rats were limited to one response (lever pressing) that was not distinguished across conditions. Lever pressing as a response exists primarily as a measure of frequency, and not of other identifying variables (such as intensity, quality, duration, etc). Mechner (1992) describes a

more specific measure of response through use of a 'revealed operant'. In an application of this procedure (Mechner & Jones, 2001), behavioural responses are identified by an individual behaviour marking the beginning of a response, the component behaviours of the response then are emitted, and an individual behaviour marks the end of a response. As responses are thus delineated, the quality of response can be evaluated in terms of number of correct components, incidence of correct sequences of components, and incidence of number of incorrect sequences of components. Use of this procedure to demonstrate history effects in an animal population would be particularly useful, and may lend insight into the specific components of the 'high variability' often seen in extinction conditions (Mechner & Hyten, 1997). Studies using this procedure have already demonstrated these effects in human populations (Mechner & Hyten, 1997; Mechner & Jones, 2001), and thus could reveal more detailed information about differences between human and nonhuman performance if replicated in nonhuman samples.

5.5 Relation of Current Results to Other History Effects

Although the current studies show little support for lasting effects of RR and RI training on FI performance, arguably this is insufficient evidence to state that lasting effects do not exist. It is possible that a latent effect on performance may resurface in subsequent contingencies, such as in extinction where behaviour often becomes more variable, and has been shown to contain some historical responses (Mechner & Jones, 2001). Although this research is conducted primarily in human populations, the latency of history effects may be far more

lasting than the FI interference shown in the current studies. That latent effects can occur in nonhumans has been shown in Chapter 4. Follow-up investigations could focus on this possibility, perhaps showing differential behaviours in extinction or even in novel paradigms. This could stretch to include not only basic schedules such as ratio and interval (as in the present study), but also manipulations of reinforcer rate, reinforcer amount, and baseline response rate.

To this end, it may be of some interest to further investigate changes of environment to include non-contingent operant environments (see Barnes & Keenan, 1989) or distracters that could serve to moderate both human and nonhuman response sets. Although FI scalloping in human samples may have been difficult to produce historically, it makes theoretical sense to focus on this population as well as the non-human population in efforts to bridge the gap between these performances. To this effect, of additional interest may also be the training of nonhumans in visually distinct responses that can then be evaluated in the context of 'revealed operants' (see Mechner et al., 1997; & Jones, 2001). By providing nonhumans with operant responses that can not only be evaluated for presence but also for speed of response, location of response, and content of response, more detailed information could be retrieved into the specificity of latent behaviours. The duration of history effects will also provide important information into learning processes in both human and rat populations, and practically informs researchers that may reuse animals without consideration of their reinforcement histories.

The current experimental proceedings show effects similar to those found in Freeman and Lattal (1992), Baron and Leinenweber (1995), and Cole (2001),

wherein effects of previous training show a transient effect on the development of response to a new continuum. In the current studies, this took the form of significantly lower rates of response in middle sessions (around sessions 6-10 for both examples). This phenomena is similar to that reported by Doughty et al. (2005). Referring to the behaviour as 'resistance to change', this behaviour is defined as "*...the persistence of responding in the face of disruption*" (p. 315), and documents the prevalence of previously reinforced behaviour even when that behaviour is no longer actively reinforced. As such, resistance to change encompasses the interfering effect of previous learning histories on normal response to new contingencies, behaviour that was experimentally demonstrated in both between and within subject animals. Nevin (2003) presents compelling evidence that resistance to change on variable-interval schedules is particularly easy to manipulate, positing a mathematical model for its presence and endurance relative to rate of reinforcement. However, some ambiguity remains as to the effects of schedule, and it is unclear how VR and VI performances differ in resistance to change where reinforcement rates were controlled.

Evidence documenting the presence of resistance to change has been compelling, showing significant instances of this phenomenon in response rate where conditions consist of higher reinforcement rate or quantity (see Nevin, 1992; 2003). This has also been shown to occur independent of response rate (Nevin, Tota, Torquato & Shull, 1990). Shull & Grimes (2006) also documented resistance to change specific to extinction paradigms, where higher or larger reinforcement during training phases resulted in greater inhibition of expected extinction responding in a rat population.

Although Lattal, Reilly and Kohn (1998) did compare resistance to change in interval and ratio schedules, no consistent differences in response rates between the conditions were found. As in the present research, however, effects were noted wherein responding persisted in interval schedules beyond that occurring on ratio schedules. The presence of differential responding patterns in these schedules of reinforcement provides further evidence for the duration of latent history effects and may be an area for further exploration.

However, it remains to be seen whether the concept of resistance to change is identical to that of other history effects; resistance to change does not, for example, reflect resurgence (where a previously learnt but not currently reinforced behaviour is displayed), nor does it address latent effects (where previous learning is not in evidence between comparison groups prior to disruption of the new contingency). To evaluate differences between these phenomena, it may be possible to compare predictions from resistance to change against those from resurgence under controlled conditions. Previous results have shown that DRL schedules can produce stronger resistance to extinction (as demonstrated by lingering history effects, and retarded development of the postreinforcement pause) than training on a ratio history (Cole, 2001). However, resurgence of DRL patterns suggests lower rates in extinction relative to interval training. Comparing DRL, FR, and FI histories on an extinction paradigm could feasibly support either prediction, and would better delineate relationships between the phenomena.

Future research could examine the differential appearance of resistance to change and resurgence in both within and between subject populations. Unlike the transient effects demonstrated in the current studies, resistance to change has been

better documented in within- (Doughty et al., 2005) rather than between- (Cohen et al, 1994) subjects design. It would be interesting to see if these phenomena act concurrently in either design, and if differences appear in interaction of resistance to change with other history effects.

The concept of history effects is not unique to instrumental conditioning procedures. Bouton (1991; 1993b) describes resurgence as primarily a function of conditioned (CS) and unconditioned (UCS) stimuli. In this model, the conditioned response is reduced when the CS is presented without the UCS after conditioning has already taken place. Although a subsequent drop in performance is observable, this is because behaviour after extinction is largely determined by environmental context; if the context is changed (this can involve changes as minor as from one location to another), a resurgence of supposedly extinguished responses can be observed (Bouton & Ricker, 1994).

Spontaneous recovery is said to occur when extinguished responding appears to return over time. Research consistently reports incidences of spontaneous recovery in animal populations (Bouton, 1993b; Thomas & Sherman, 1986). The reappearance of previously trained and then extinguished responses that defines spontaneous recovery indicates a latent effect of history on behaviour, although whether this occurs due to strength of pretraining, or failure of extinction, as yet remains to be seen (Bouton, 1993b). Further, it is suggested that some of the recovery of previous responding seen in spontaneous recovery may simply be due to the passage of time (Bouton, 1993b; Thomas & Sherman, 1986), where inhibitory effects atrophy as time since extinction increases. The concept of inhibition as a declining effect could be particularly interesting in the context of

theories of history effects as inhibition-linked, wherein schedules with high inhibition (such as DRL) transfer most easily to similarly high inhibition schedules (Cole, 1991).

5.7 Demonstrating History Effects With More Detail

History effects are most easily seen in either extinction, or removal of response-dependent reinforcement paradigms, where subjects display previously learnt behaviours once the most recently learnt behaviour has failed. The vast majority of studies evaluating the role of history effects follow a basic procedure, wherein subjects are first exposed to different reinforcement schedules, then exposed to identical reinforcement schedules, utilising the same apparatus and stimuli. Effects are then demonstrated based on rates of response in the second condition. However, given this basic structure, little information is given about the nature of the history effects save that of response rate; there is, for instance, little evidence documenting how qualitatively different responses may show resurgence in similar circumstances.

By training 'operants' as a sequence of keystrokes 'book ended' by behavioural events, Mechner and Jones (2001) demonstrate some evidence that specific history effects are moderated by antiquity (defined as the 'age' of the operant in an individual's learning history). In this case, however, high incidences of resurgence occurred with simultaneously high incidences of novel keystroke sequences, indicating an overall highly variable level of responses emitted. By using a procedure in which an operant consisted of a clearly delineated set of

behaviours that included both beginning and ending markers, the incidence and variability of a particular response set was particularly well recorded.

Thus far, similar comparisons of operants as sequenced behaviours — that is, reinforcement on a particular schedule following a unique sequence of similar behaviours rather than a discrete example of a particular behaviour (e.g., Epstein, 1983; Lieving & Lattal, 2003) — has not been demonstrated in an animal population. This may be due to the relatively limited measurable behaviour of such populations in comparison to human populations, making measurement of such sequences difficult. Future research could examine this phenomenon in non-human subjects, using a sequence of levers (for rats) or key pecks (for pigeons). Such research would provide a closer examination of how history effects function cumulatively, as a number of uniquely defined sequences could be trained and their subsequent resurgence measured based on these definitions. The demonstration of numerous historical contingencies would better replicate naturalistic learning experiences for both humans and non-humans, and may shed light on the interaction between schedules of reinforcement on resurgence of behaviours.

5.8 History Effects in a Clinical Context

To apply history effects to a human population, the continuity hypothesis must be met: that is, one must accept that, to some degree, animal models will relate in significant ways to a human sample (Hayes & Hayes, 1992). Having accepted this, a number of behavioural history effects can be demonstrated in patient populations. This is particularly true of primacy and recency, which can be

used to differentiate between normal and abnormal memory function. For example, primacy and recency have been used to distinguish differences in Alzheimer-type dementia, with impairments shown for primacy but not for recency effects (Burkart, Heun, & Benkert, 1998). Using a similar paradigm (list recall), Bayley et al. (2000) demonstrated significantly reduced primacy effects, but normal recency effects, in Alzheimer's patients as compared to a normal control. This research effectively uses history effects (primacy and recency) to isolate differences in learning between patient and normal populations, information that can then be used in diagnosis, early identification, prognosis, and treatment.

Behaviour theory and in particularly behaviour analysis has long been applied to effect change in humans with developmental disabilities (Lovaas, 1993). This type of treatment generally uses basic principles of learning, including reinforcement on various schedules to encourage desirable behaviours, and discourage undesirable behaviours. However, as noted in the discussion of human as compared to nonhuman response patterns, humans are exposed to an expansive history of various schedules of reinforcement that are not standard across individuals (Weiner, 1969; 1970a). The vast history then acts as a context for later learning, and is particularly implicated in individuals treated using behaviour analysis. Lattal and Neef (1996) argue that it is precisely this history that interacts with treatment outcomes. As such, individuals with a less extensive and variable behavioural history will respond in more predictable and easily modified ways to contingencies applied in treatment, whereas those with more complicated histories will show less sensitivity to new contingencies. It is

suggested that this may account in part for findings that positive outcome in the treatment of autism is highly related to younger ages at treatment onset (Lovass, 1993).

Drug studies on behavioural history have defined habitual behaviour as a relation between past and current use of a drug, with a model for development of addiction as dependent on building on previous histories of use (Gavrila, Feichtinger, Tragler, Hartl, & Kort, 2004). As any other behaviour, drug-seeking is also considered to operate on given schedules of reinforcement (Kelleher, Goldberg, & Krasnegor, 1976). Research supporting differential effects of drugs based on different historical experience supports the view that drug reinforcers operate similarly to any other reinforcer (Wiener, 1981), and can thus be seen as exhibiting history effects similar to those seen in schedules (Cole, 2001; Lopez & Menez, 2005; Wanchisen et al., 1989) or sequenced behaviours (Mechner & Jones, 2001).

Barrett (1977) found significant differences for effects of *d*-amphetamine in punished and unpunished responding. Here, animals with histories high in avoidance showed rate increases on *d*-amphetamine during punishment, whereas animals without avoidance histories showed rate decreases. Similarly, Urbain, Poling and Thompson (1978) reported effects of *d*-amphetamine on lever pressing continua, showing differences between DRL and FR groups reflecting those found by Barrett (1977) for avoidance trained and non-avoidance trained groups.

The clear interaction of reinforcement history and response decreases following drug administration suggests that future analyses on history effects in psychopharmacology would be appropriate. Weiner (1981) suggests that future

directions of drug studies should focus on this interaction. Specific work is suggested wherein consistent drug effects can be controlled through tighter control over behavioural history, as well as explaining individual differences in drug response based on historical contingencies even in the presence of identical current contingencies. This could be of considerable interest in studies of behavioural inhibition. Previous studies have shown some evidence that schedules with inhibitory effects (such as DRL) show easier transitions to new contingencies with similar effects (Cole, 2001). Comparing the interaction between behaviourally inhibitory response and physiologically inhibitory responses (through drug administration of either stimulants or depressants) may show some continuity between biological and environmental processes. Further, these effects may be present in both human and nonhuman samples, thus supporting continuity between the species.

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